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Marine Environmental Conditions off the Pacific Coast of the United States, January 1977-March 1978

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Introduction

During 1977 and early 1978 unusual atmospheric circulation occurred over the northeast Pacific. In both winters (1976-77 and 1977-78) strong and persistent high pressure ridges in the atmospheric circulation formed over the west coast of North America. The atmospheric circulation had a variety of effects on local oceanographic conditions and fishery resources in the region.

As a result of the ridge circulation during both winters, southerly winds of moist, warm air blew over Alaska and the eastern Bering Sea. This caused the coastal waters of the southeastern Bering Sea and the western Gulf of Alaska to be much warmer than normal. The warm weather broke a 6-year cold spell (1971-76) which had had serious effects on fisheries in the Kodiak Island region and the southeastern Bering Sea. The warm waters of 1977-78 should allow rapid growth of juvenile salmon, halibut, and other species. Herring spawning may be advanced by 1-2 weeks. Abundant precipitation fell over Alaska. Wind driven surface transport caused surface waters to be held near the coast of the Gulf of Alaska. This convergence combined with the dilution from precipitation and runoff to increase coastal longshore circulation in the Gulf. Increased advection of waters from the south transported salpae into waters off southeastern Alaska in May and June 1978.

Off the west coast of the contiguous United States, the circulation associated with the atmospheric pressure ridges was dissimilar in the two winters. During the winter of 1976-77, a high pressure system persisted off the California coast which diverted storms to the north. Calm, clear weather under this high pressure system produced record drought over California and warmed coastal waters. Upwelling off the California coast was moderate.

In contrast, during the winter of 1977-78 the ridge over Alaska moved northwestward, the high pressure system off California was absent, and a weak trough occurred off the west coast. The trough allowed storms to come into the coastal zone and bring abundant precipitation to California, breaking the drought. Airflow was more southerly than normal causing coastal convergence and possibly increased flow of the Davidson Current. Occasional strong downwelling pulses occurred. The coastal convergence broke a 5-year run of strong upwelling. Due to the convergence and to possibly increased Davidson Current, coastal waters were again warmer than normal. Also due to the coastal convergence, eggs of winter spawners such as anchovy would have been held nearer the coast than normal and may result in better than normal survival.

Cooler than normal water occurred throughout the period in an extensive area of the central North Pacific near lat. 40°N and long. 150°W. Strong winds over this region during the winter of 1976-77 appear to have strengthened the transport of the West Wind Drift Current. Low salinity water occurred in the California Current during 1977 and especially so in 1978, suggesting anomalously great advection of low salinity, subarctic water from the north and increased local precipitation. Associated with this change was a weakening of salinity fronts of the Transition Zone in 1977. Fronts in the Transition Zone in early 1978 were near normal.

Sea surface temperatures in the eastern tropical Pacific decreased during early 1977 from the anomalously high temperatures that resulted from a moderate El Niño in 1976. Sea surface temperatures were lower than normal off Peru and along the Equator from April to September 1977 and during early 1978, possibly due to increased upwelling. Temperatures off Baja California were above normal in early 1977 due to excess solar insolation and were again above normal in early 1978 due to weak upwelling. Wind mixing and tropical storms reduced surface water temperatures along the coast of Central America during 1977 and early 1978. Strong winds and the response of tuna fishermen to porpoise regulations contributed to below normal tuna catches during 1977.

Atmospheric Variations

The dominant feature of the atmospheric circulation over the northeast Pacific Ocean during January 1977 to March 1978 was the presence during the winters of 1976-77 and 1977-78 of persistent and intense ridges of high atmospheric pressure over the west coast of North America. The January circulation, as depicted by the heights of the 500-mb pressure surface, is

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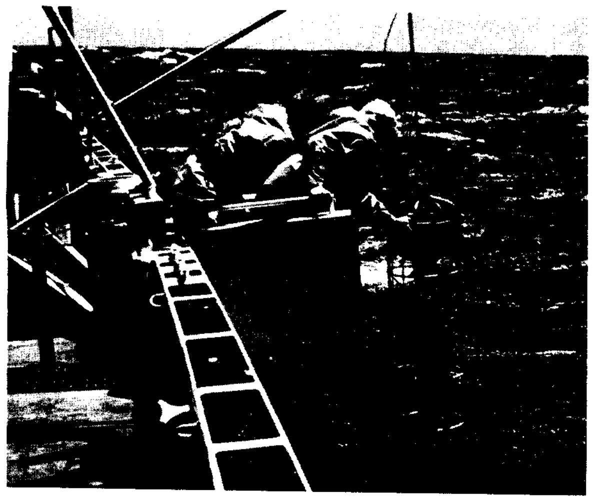


Fishery technicians (left and right above) launch instruments to measure oceanographic conditions. Temperature and salinity variations reveal such important ocean processes as upwelling, ocean front formation, and current changes. Yellowfin tuna (bottom right), ranging across broad reaches of the eastern tropical Pacific Ocean, are sensitive to specific ranges of temperature and oxygen. Fishermen monitor the vertical ocean temperature structure as an important tactic in fishing for them.

representative of each winter (Fig. 1). The upper air ridges resulted in the advection of warm, maritime air northward over the northeast Pacific and bought southerly winds and mild conditions to the south coast of Alaska. A persistent blocking high pressure cell was present off California during much of 1977 and diverted storms to the north. During the winter of 1977-78 the ridge structure was expanded and shifted to the northwest over Siberia and Alaska and a weak low pressure trough was present off the west coast. Southwesterly winds associated with this trough then brought storms onto the west coast of the United States. Downstream from the persistent ridges along the west coast northerly winds blew over the eastern United States, producing record cold and snowy winters. The ridges in both winters were somewhat similar to the ridge that occurred during the winter of 1957-58 which brought warm coastal waters to much of the west coast of North America and cold weather to the eastern United States (Johnson and McLain, 1975). Namias (1978) described the unusual atmospheric circulation of the winter of 1976-77, its relations to ocean conditions, and multiple causes for its formation.

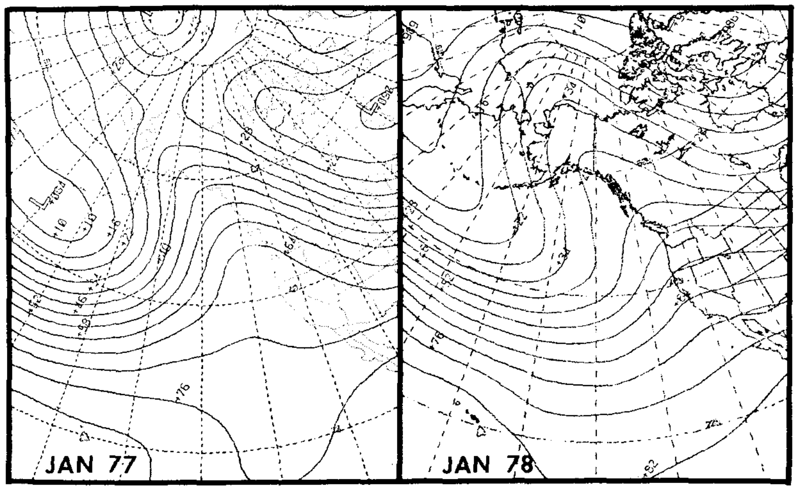


Figure 1.—Heights of 500-mb pressure surface (in tens of meters, +5,000 m) in January 1977 and January 1978. Contour lines are at 60-m intervals.

At the ocean surface, beneath the ridges of upper air circulation, the distribution of surface barometric pressure indicates the surface winds which drive the ocean currents. Figures 2, 3 show the surface pressure patterns and winds over the Northeast Pacific during the winters of 1976-77 and 1977-78 (January data are again taken as representative). The Aleutian low pressure system is the dominant winter feature of the surface circulation over the North Pacific and in both winters the Aleutian low was deeper than normal (Fig. 2, 3, lower). This anomaly of low pressure had been characteristic of the last quarter of 1976 and lasted through February 1977. The anomaly pattern became reestablished in January 1978 and lasted through April.

During the 1976-77 winter the normally weak high pressure cell of California was elongated and extended northward over Oregon, Washington, and British Columbia (Fig. 2, upper). The resulting intensified atmospheric circulation advected warm maritime air toward the southern Alaska coast where record mild temperatures and abundant rainfall occurred. Under the high pressure cell, winds were weak, clear weather prevailed, and record drought occurred in California.

In the winter of 1977-78, a deepened Aleutian low extended far to the east of its normal position and the high pressure cell off California was absent (Fig. 3, upper). This circulation directed storms over the west coast of the United States and resulted in record or near record rainfall, breaking the California drought. During the intervening seasons, barometric pressure patterns and associated winds were closer to normal than during the winters.

Gradient and Vector Winds

The relative intensity and direction of surface winds over the northeast Pacific during the winters of 1976-77 and 1977-78 is shown by isolines of surface barometric pressure and their gradients (Fig. 2, 3). Also shown in the figures are arrows, which in the upper half of the figures represent the direction of resultant average vector winds and in the lower half of each figure represent the departure of each vector wind from its long-term average.

The westerly winds south of the deepened Aleutian low were stronger than normal west of long. 150°W in the last quarter of 1976 and first 2 months of 1977 (e.g., January 1977, Fig. 2). Between long. 130° and 150°W there was a strong southerly component to the winds and the general marine conditions were characterized by high winds, high seas, and storms. East of long. 130°W, conditions were relatively mild. By March the subtropical high pressure cell off California had intensified, producing strong northerly winds along the coastal region and causing a strong pulse of coastal upwelling from Baja California northward to Alaska. Winds were near normal over extensive areas of the eastern North Pacific Ocean through July. For 3 months beginning in August the Aleutian low alternated between a deepened and relaxed condition in the area west of long. 135°W. East of long. 135°W winds were near normal. In December, a southeastward shift of the Aleutian low and a weakening of the high pressure cell brought southerly moist winds to the California coastal regions.

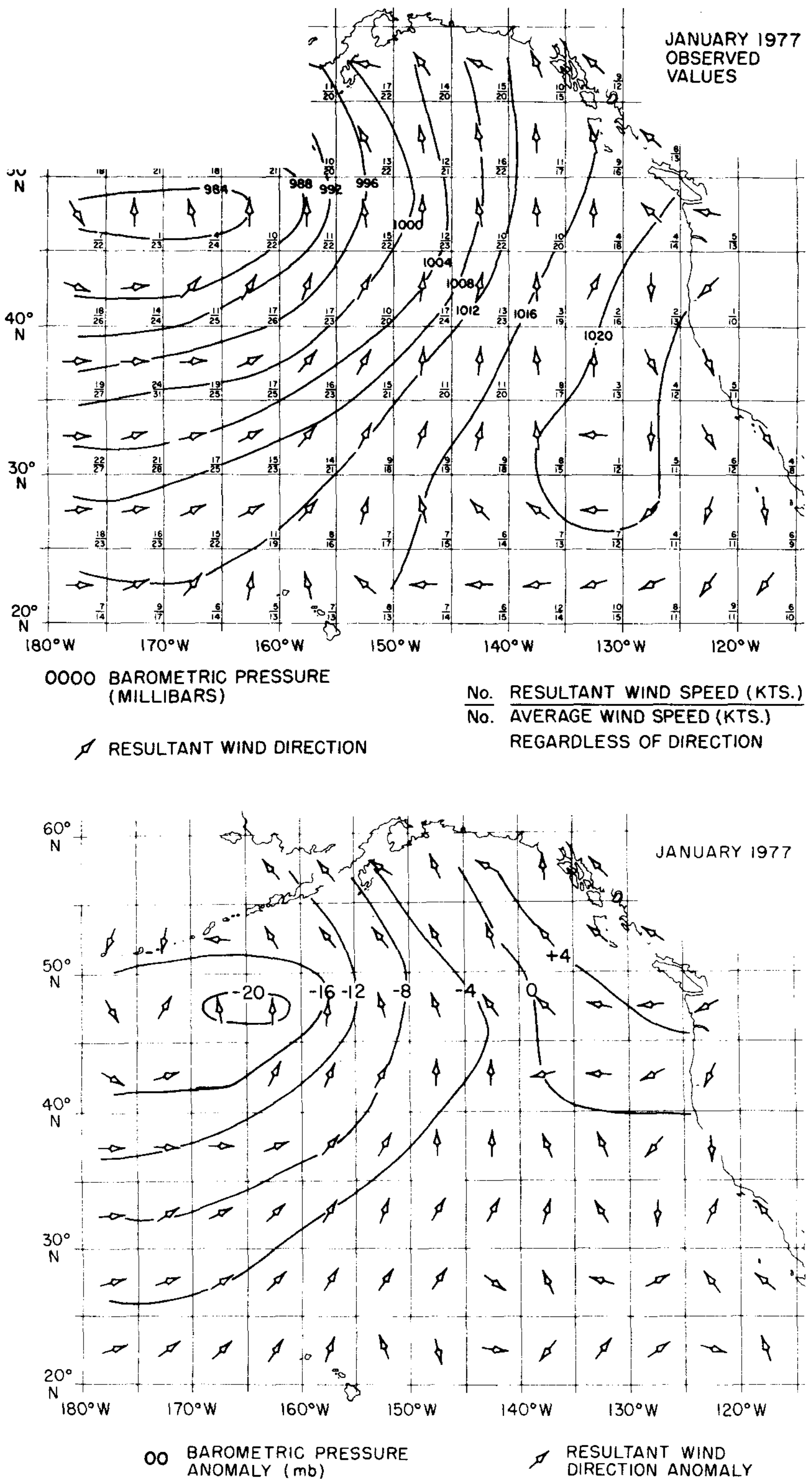


Figure 2.—Upper—Sea level barometric pressure (millibars), resultant wind direction (degrees true), resultant wind speed (knots), and average wind speed (knots) regardless of direction for January 1977 (from *Fishing Information*). Lower—Departure of sea level pressure (millibars) from the long-term mean (calculated from 1961 through present year) and departure of resultant wind direction from long-term mean for January 1977 (courtesy of J. Renner).

Ocean Surface Transport and Upwelling

The polar easterlies, mid-latitude westerlies, and subtropic easterlies (trades) are terms describing long-term averages of prevailing winds over the oceans. Beneath these zonal regions of winds lie the major ocean currents that flow over great distances in much the same direction as the winds. In the northeast Pacific the major wind driven currents are the West Wind Drift Current, the Alaskan Stream, the California Current, and the North Equatorial Current. The surface layer transports associated with these currents has been computed from classical Ekman theory based upon monthly average wind data.[1] Although Ekman transport estimates form only a portion of the total ocean circulation, they suggest the monthly and seasonal influence of the winds. The 20-year averages of monthly transports at each of four selected locations in the northeast Pacific during 1977 and early 1978 are shown in Figure 4.

In the offshore region (e.g., lat. 39°N, long. 149°W; Fig. 4, lower), strong westerlies in winter strengthen the West Wind Drift. At lat. 27°N, long. 140°W subtropic easterlies may strengthen the North Equatorial Current in summer. During January and February of both 1977 and 1978

[1]Computations of surface layer transport prepared by Andrew Bakun, Pacific Environmental Group, NMFS, NOAA, Monterey, CA 93940. Values are computed on a grid of 3° latitude and longitude from data of Fleet Numerical Weather Central, Monterey, CA 93940.

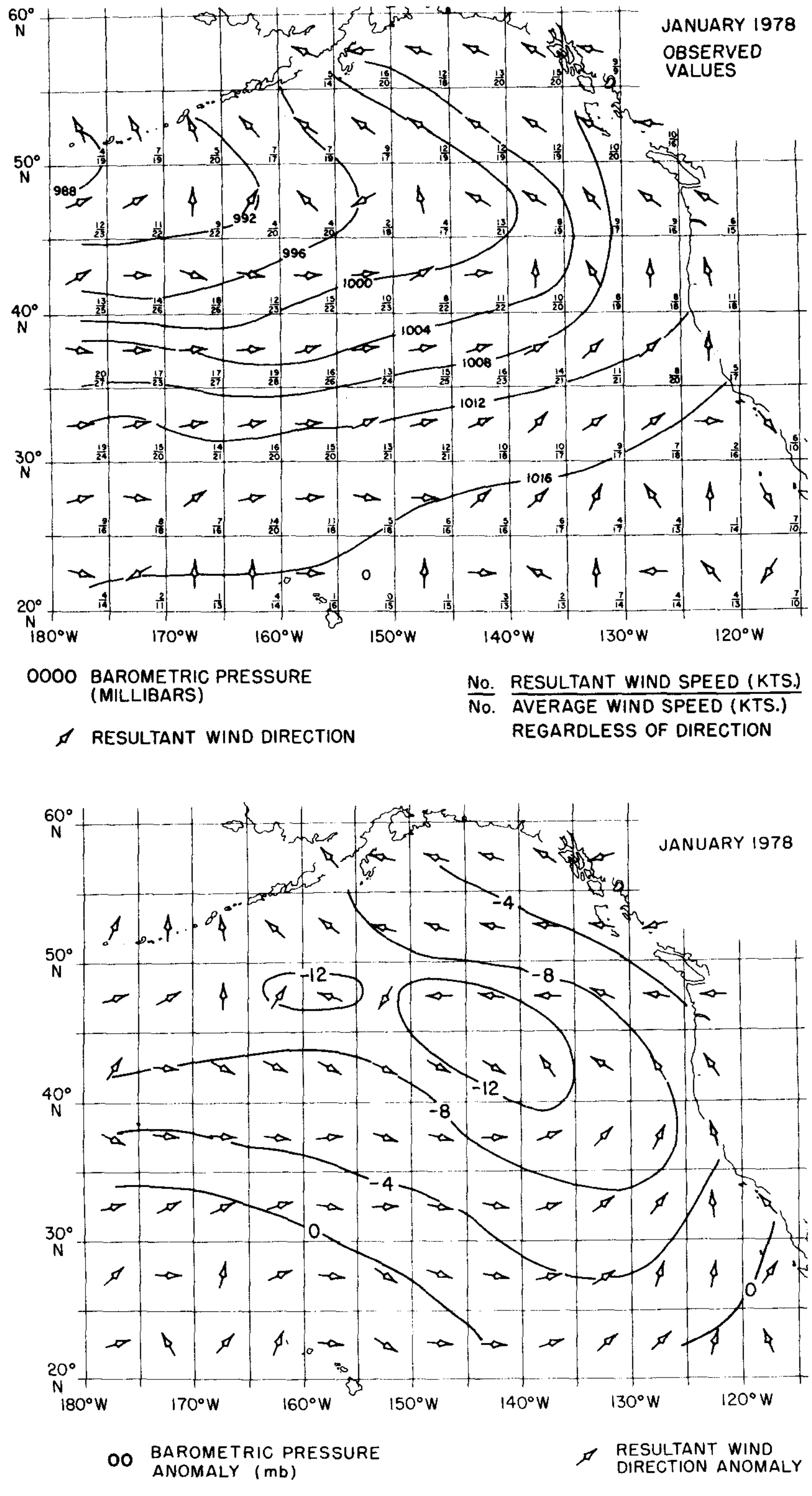


Figure 3.—Upper—Sea level barometric pressure (millibars), resultant wind direction (degrees true), resultant wind speed (knots), and average wind speed (knots) regardles of direction for January 1978 (from *Fishing Information*). Lower—Departure of sea level pressure (millibars) from the long-term mean (calculated from 1961 through present year) and departure of resultant wind direction from long-term mean for January 1978 (courtesy of J. Renner).

(Fig. 4, upper) transport at lat. 39° N, long. 149° W was very large and directed to the southeast. At lat. 27° N, long. 140° W where southeast winds normally drive the waters to the north, the transport for the same time periods was weak or southward. Thus in both winters and over a broad offshore region, the winds acted to intensify the West Wind Drift Current and the southeastward flow of the California Current. Low salinities in the California Current (discussed in a later section) may have, in part, been a result of greater than normal intrusion of subarctic waters, caused by strengthened advection. Transport during the intervening months was near normal with the exception of March 1977 at lat. 27°N, long. 140°W when the intensified subtropical high strengthened the southeast trades, producing large transport toward the northwest.

Along the coast, surface transport moves water onto or away from the coast and causes vertical movements of water known as upwelling (or downwelling)—a process of great biological significance. The northwest winds prevailing in summer along the coast from Oregon southward to Baja California (e.g., lat. 39°N, long. 127°W) cause surface transport offshore and replacement by cold, nutrient rich water upwelled from below. The nutrients in this water support the abundant biological productivity in the area. Along the Alaska coast (e.g., lat. 57°N, long. 140°W) transport is onshore during much of the year.

Onshore-offshore transports also affect the strength of coastal currents.

The effect of upwelling (and downwelling) forces a compensatory flow elsewhere in the water column which affects the density structure (baroclinicity) and, hence, geostrophic flow. In periods of increased coastal upwelling where there is anticyclonic flow (i.e., California Current) the flow is strengthened, and in periods of increased coastal downwelling where there is cyclonic flow (i.e., Alaskan Stream) the flow is similarly strengthened.

Transports computed for 1977 and early 1978 for the coast of northern California at lat. 39° N, long. 128° W show that there was anomalous offshore transport during March, June, and July 1977 and anomalous offshore transport during December 1977 through February 1978. Thus during March, June, and July there was increased upwelling and, possibly, a strengthened California Current near the coast. During the subsequent winter there was downwelling and possibly a stronger nearshore countercurrent. During a typical winter, the current seasonally weakens and shifts away from the coast while the poleward flowing California Undercurrent surfaces as a countercurrent (Davidson Current) in the near-coastal regions. In the subject winters each of these events may have been enhanced. One consequence of the onshore transport during early 1978 would have been to hold eggs and larvae of winter spawning fish such as anchovy closer to the coast than normal. This may be desirable for good survival.[2]

In the Gulf of Alaska at lat. 57° N, long. 140° W, winds during both winters acted to strengthen the normal seasonal onshore transport, strengthen coastal downwelling, and probably also enhance westward geostrophic flow in the Gulf of Alaska. The abundant precipitation of both winters caused dilution of coastal surface waters in the area and probably acted to further strengthen the enhanced

[2]Parrish, R. H., and C. S. Nelson. 1976. Larval transport mechanisms in the California Current. Presented at California Cooperative Oceanic Fisheries Investigations Conference, Indian Wells, Calif., November 16-18, 1976.

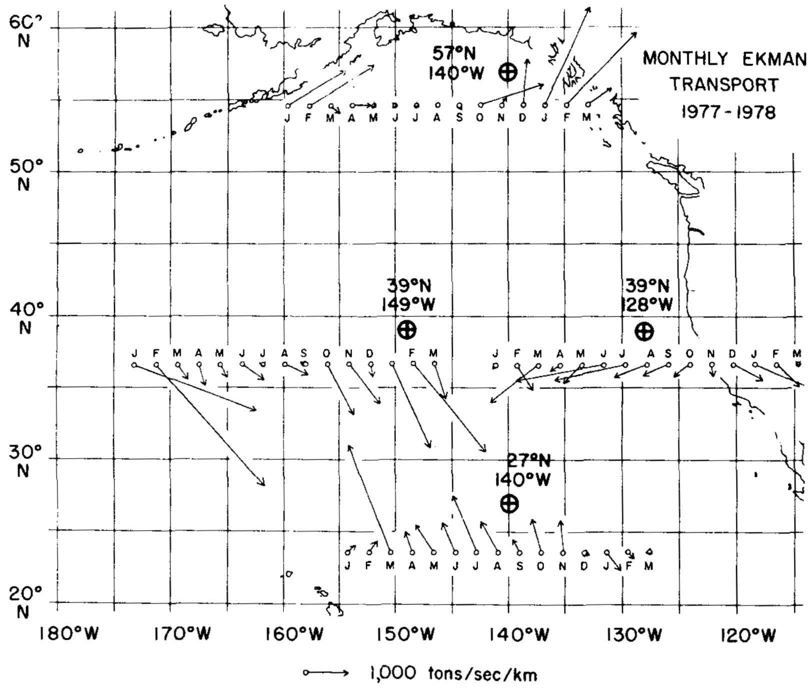
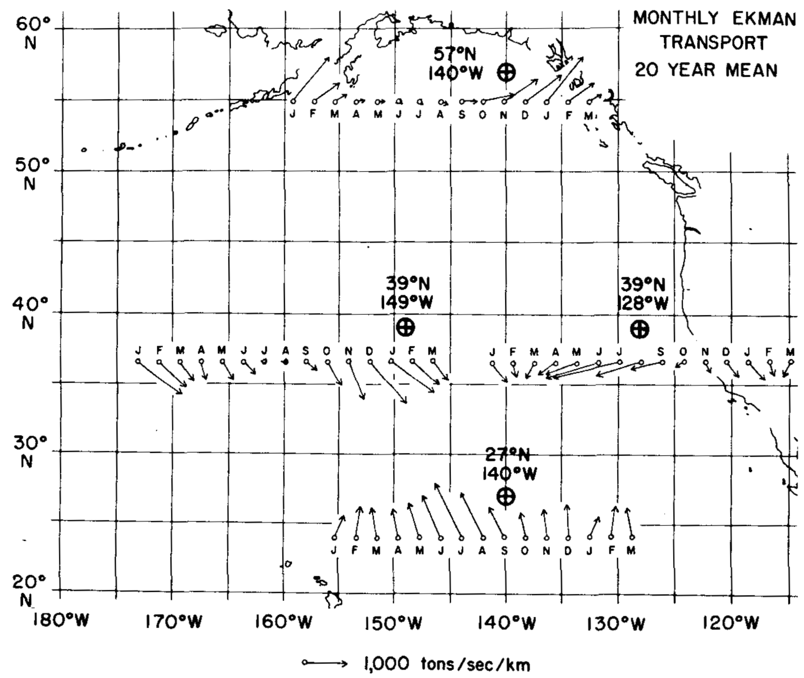


Figure 4.—Vectors of monthly Ekman transport for four areas of the eastern North Pacific, computed over a 3° square of latitude and longitude for January 1977 through March 1978 (upper) and for monthly means over a 20-year period (lower).



flow. Observations of clear, warm oceanic waters with abundant salpae off southeastern Alaska during May and June 1978[3] are explained by the increased flow.

The details of variations of upwelling with distance along the coast are of particular interest. Bakun (1973) has computed the component of Ekman transport normal to the coastline as an index of the intensity of upwelling. This computation is made at 15 points along the coast from lat. 21°N off Mexico to lat. 60°N on the south coast of Alaska. Time-space variations of the upwelling as indicated by the upwelling index are shown in Figure 5 as percentiles of historic normal values.

Very strong upwelling occurred off northern California during January to November 1977. Upwelling index values at lat. 39°N for March, June, and July of 1977 were the highest for those months in the 32-year (1946-77) period of record. Only in May and after November did the values at lat. 39°N fall below the median for the month. Thus 1977 continued an unprecedented series of 5 years of strong upwelling off northern California which had begun in 1973.

In contrast to the generally strong upwelling of 1977, during early 1978 downwelling occurred along the California coast as previously mentioned. This downwelling is indicated on Figure 5 as extremely weak upwelling. The downwelling period broke the run of 5 years of strong upwelling mentioned above. The downwelling or weak upwelling began in December 1977 off California and extended along the entire coast from lat. 24° to 60°N, except for a minor peak in March at lat. 45° to 48°N. Off central California (lat. 30° to 36°N) the upwelling index was the lowest that had occurred during the period of historical record at 6 month-locations.

The upwelling off southern Baja California (at lat. 21°N and to a lesser extent at lat. 24°N) was persistently strong throughout the period. During February to August, upwelling index values at lat. 27°N and southward have been in or near the upper quartile of the various month-location distributions. At the southermost point (lat. 21°N) the index was in the 95th or higher percentile throughout the period.

Widespread anomalies occurred in March and May 1977. Very high upwelling index values during March extended south of lat. 21°N off southern Baja California to lat. 60°N in the northern extremity of the Gulf of Alaska (where they indicate abrupt relaxation of the winter downwelling situation). During May, values were very low from off the Washington coast southward to northern Baja California but high in the Gulf of Alaska and off southern Baja California.

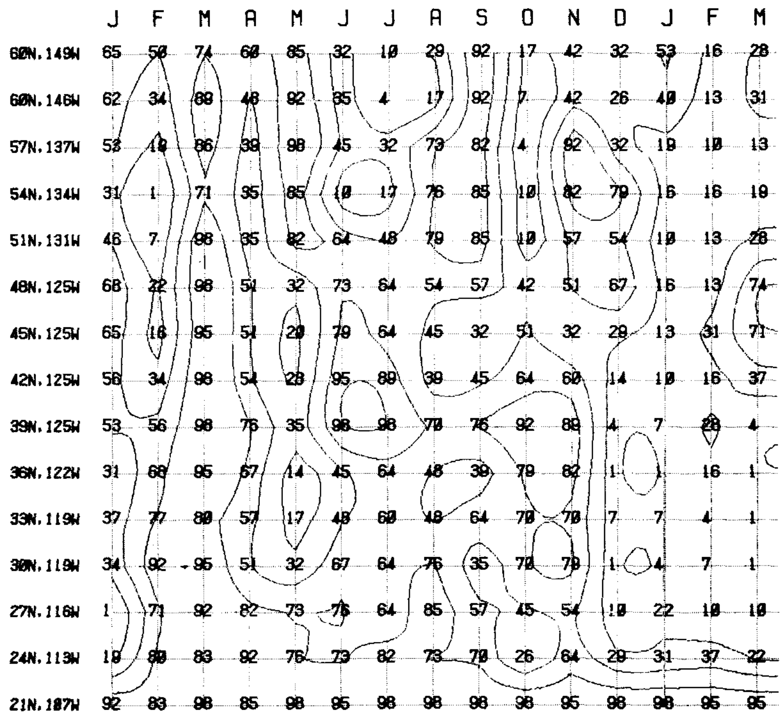


Figure 5.—Monthly upwelling index values for January 1977 to March 1978, in percentiles of the frequency distributions made up of the 32 values for each month and location in a 32-year (1946-77) time series. Locations in the Gulf of Alaska are toward the top of the figure; those off Baja California are toward the bottom. The contour interval is 25 percentiles. Values above the 50th percentile indicate stronger than normal upwelling while those below indicate weaker than normal upwelling.

Sea Surface Temperature

Over the North Pacific, sea surface temperature (SST) increases predominately from north to south (Fig. 6). The nearly zonal pattern of isotherms of SST over the North Pacific mid-latitudes is deflected near the west coast by advection and upwelling. There is a northward bending of isotherms into the Gulf of Alaska and a southward bending from Oregon to Baja California. The deflection is greatest in summer months.

Over much of the open ocean in temperate latitudes the annual minimum in SST is reached during March (Fig. 6, upper) and the maximum is reached during September (Fig. 6, lower). The amplitude of the seasonal variation of sea surface temperature ranges from a high of about 10°C in

[3]Bruce L. Wing, Northwest and Alaska Fisheries Center, NMFS, NOAA, Auke Bay, AK 99821, pers. commun.

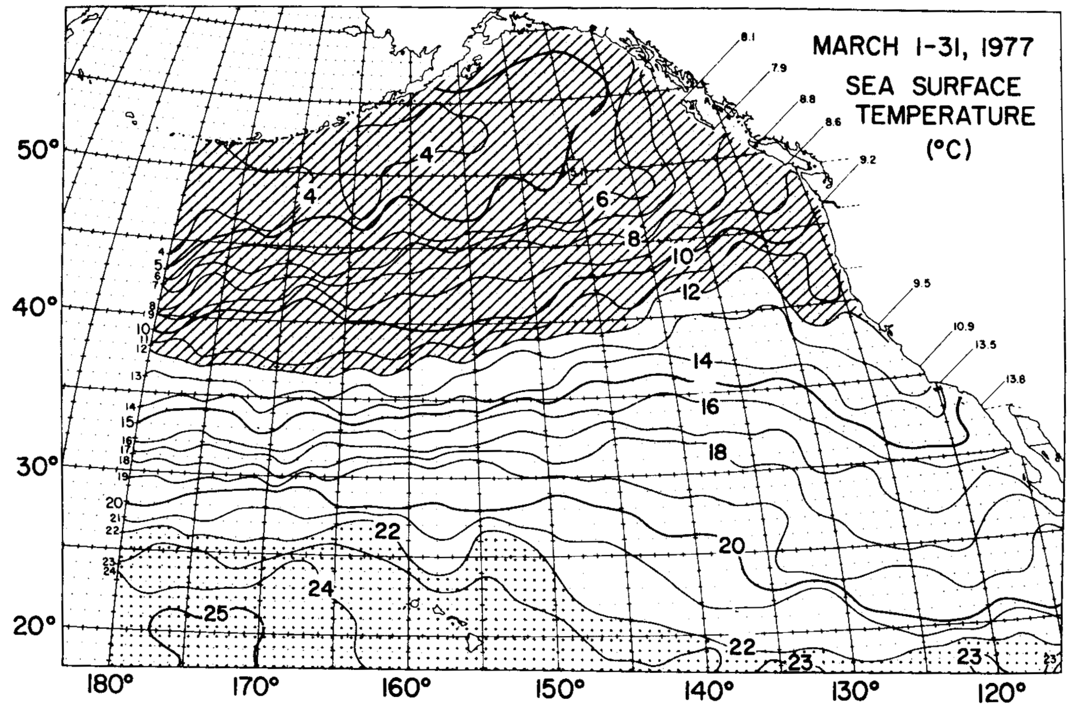
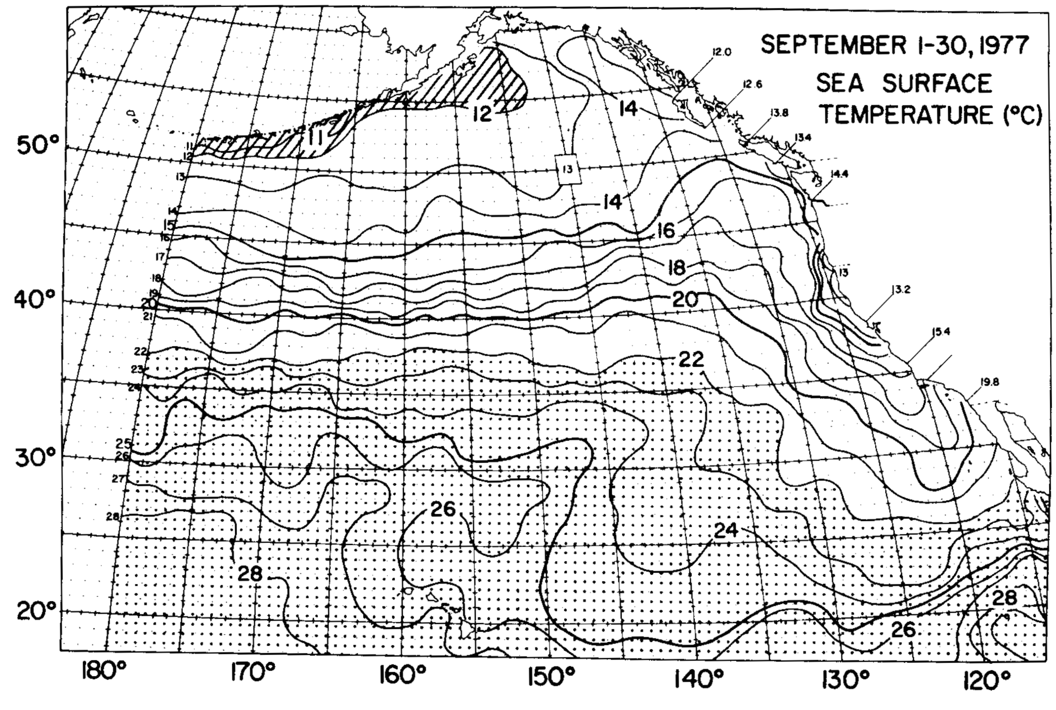


Figure 6.—Sea surface temperature for the eastern North Pacific during March 1977 (upper) and September 1977 (lower), adapted from *Fishing Information*.



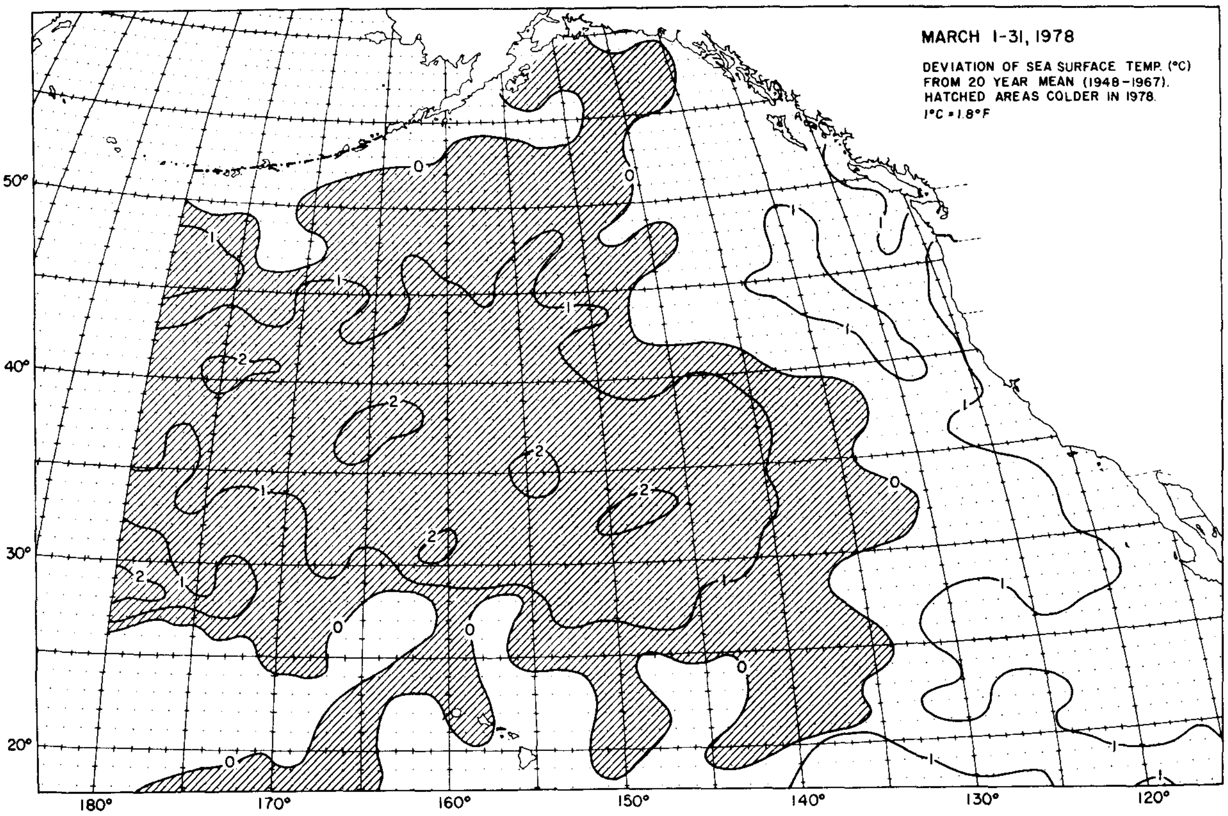


Figure 7.—Anomaly of sea surface temperature (°C) for March 1978 from the 20-year monthly mean (1948-67). Hatched area was colder in 1978 than long-term mean (from *Fishing Information*, March 1978).

the mid-latitude zone where the meridional temperature gradient is greatest to 8°C in the Gulf of Alaska and 5°C in the subtropics. In the coastal region the amplitude of variation is much reduced by upwelling of cool waters during summer (Oregon and south) and slightly reduced by downwelling in winter along the Alaska coast.

Contoured charts of the anomaly of SST (the departure of SST from the 20-year monthly mean) for the eastern North Pacific are published monthly in *Fishing Information.*[4] In all but 1 of the 15 monthly SST anomaly charts published for 1977 and early 1978, a large body of cooler-than-normal water appeared roughly centered in a band along lat. 40°N between long. 175°E and 150°W. (The chart showing this feature for March 1978 is reproduced here as Figure 7.) Latitude 40°N is about the axis of the West Wind Drift Current and the latitude of a large north-south gradient in temperature. Eber (1971) described the frequent occurrence of persistent large-scale SST anomalies between lat. 30° and 50°N in the North Pacific Ocean and proposed that they were produced by a quasi-stationary wave pattern in the West Wind Drift Current. A southward displacement of the Current in mid-Pacific and northward displacement east of long. 150°W could have produced, in a gross sense, the negative temperature anomaly pattern found during 1977 and early 1978. The development of this feature had begun during the latter half of 1976, hence it was a phenomenon having a longer time scale than that of the monthly variations in wind-induced Ekman transport.

Details of the variation of sea surface temperature along the coast are discussed later for individual sections of coastline. In general, however, coastal SST variations were characterized by broad regions of positive anomalies during the early months of both 1977 and 1978. In March 1977 coastal regions were near normal and by April they were cooler than normal. For the remainder of the year the coastal region was generally cooler than normal, especially in November. In December there was a relaxation of the negative anomalies and an excessive warming off Baja California. By January the coastal region from Baja California to southeastern Alaska was

[4] *Fishing Information*, published monthly by Southwest Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.

again warmer than normal. The positive anomaly grew in magnitude and extent through March 1978 (Fig. 7).

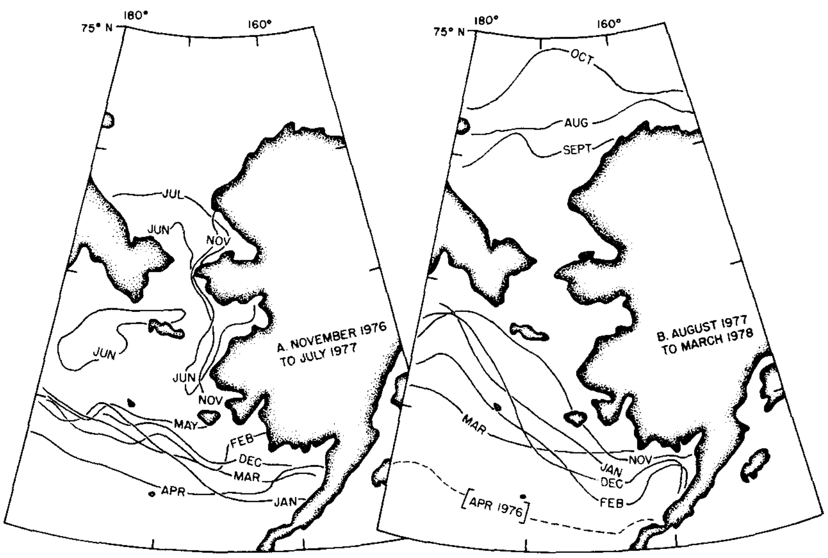


Figure 8.—Mid-month locations of ice front in eastern Bering and Chukchi Seas during November 1976 to March 1978 and, for comparison, April 1976. Plotted from data of the National Environmental Satellite Service and from ice cover analyses from U.S. Navy Fleet Weather Central, Suitland, Md.

Eastern Bering Sea

The Bering Sea is a deep ocean basin separated from the open North Pacific Ocean by the Aleutian Island Chain. In the eastern portion of the basin there are extensive areas of shallow water supporting abundant fishery resources. The oceanography of the shallow areas is dominated in the winter and spring by the extent and duration of ice cover and in spring and summer by heating and river discharge. Fast moving, intense storms originating in the North Pacific Ocean as well as locally have major effects on ice cover, runoff, and ocean currents.

Oceanographic data from the area are scarce and there are relatively few routine observations of oceanographic conditions due to the remote location and to winter ice cover. Air temperature records at weather stations, river discharge measurements, and scattered observations at a few coastal stations are the only long-term data available.

Ice

The extent of ice cover in winter and the timing of ice breakup in spring are important environmental factors affecting fishes and fisheries in the eastern Bering Sea. Satellite infrared imagery and weekly charts of ice distribution issued by the U.S. Navy and National Environmental Satellite Service (NESS) provide information on ice conditions in the eastern Bering Sea. A graphical representation of the mid-month positions of the ice edge, based on the Navy and NESS data, is shown in Figure 8 for the ice seasons of 1976-77 and 1977-78. For comparison, the position of maximum ice extent during the previous season (1975-76) is also shown on Figure 8. Overall, ice cover was above normal in winter and spring 1977 and normal or even slightly above normal in late fall 1977, but below normal during the winter of 1977-78. Only small amounts of ice remained in embayments on the north side of Bristol Bay in late March. In addition, the breakup of lake ice in the area is expected to be early.

Temperature

Air temperatures over the eastern Bering Sea during 1977 and early 1978 were generally warmer than normal as a result of southerly winds associated with the persistent high pressure ridges in the upper air circulation. Anomalies of air temperature at St. Paul Island in the Pribilofs were positive in 8 out of 13 months in which data were available in 1977 and early 1978 and ranged up to 4.1°C above normal. Temperatures farther north along the coast at King Salmon, Nome, and Kotzebue also were generally above normal, particularly in early 1977 and early 1978. In January 1977, King Salmon, Nome, and Kotzebue all observed air temperatures 9° to 11°C above normal. This was the warmest January on record at King Salmon and Nome.

Thus 1977 and early 1978 broke a stretch of 6 years (1971-76) in which temperatures in the southeastern Bering Sea were much below normal. Stocks of such marine species as sockeye salmon and halibut were adversely affected by the cold years (McLain and Favorite, 1976). The warm conditions of 1977-78 should allow more rapid than normal growth rates of salmon and halibut in the Bering Sea and of juvenile salmon in tributary streams and lakes.

The water of the eastern Bering Sea is isothermal during winter with temperatures throughout the water column during winter of -1.8°C under the ice and 1°-3°C just north of the Alaska Peninsula, depending on the southern extent of the ice cover. Warming in spring and summer of the surface layer closely parallels increasing air temperatures, but dilution from ice-melt and rapidly increasing land runoff quickly stabilizes the water column and confines further warming to the upper 20-30 m. Thus, bottom temperatures generally reflect the extent of ice cover until late summer and early fall when horizontal advection and downward diffusion of heat can increase bottom temperatures prior to winter overturn and seasonal ice formation.

In general, bottom temperatures in the eastern Bering Sea were considerably warmer in 1977 than in 1976 (or much of the 1970's). Data from NMFS research surveys[5] and other vessels indicated that bottom temperatures in the corridor into Bristol Bay north of the Alaska Peninsula were near normal (about 3°C) during late spring and early summer 1977. In spring 1976 temperatures of less than 0°C had occurred and apparently hindered the eastward onshore movement of halibut (Favorite et al., 1977:151[6]).

Runoff

There are six major rivers discharging into the eastern Bering Sea. These rivers and their average annual flows (100,000 cubic meters per second) are: Yukon (17.6), Kuskokwim (4.6), Kvichak (0.4), Kuzitrin (1.3), Wood (0.6), and Nuyakuk (0.6). Although ice jams in spring (not only in the rivers but at the river mouths) influence the freshwater discharge from the extensive snowsheds, ice breakup usually occurs in the low flow lowland rivers (Egegik, Naknek) by mid-April, in the Kuskokwim Bay by 1 May, and the entrance to the Yukon River by early June.[7] In May, the mean daily discharges of most rivers increase an order of magnitude (e.g., for the Yukon River from about 700 to 17,000 cubic meters per second and for the Kuskokwim River from 300 to 2,800 cubic meters per second); maximum values have been maintained at times until summer.

Although runoff data were only available through September 1977 at the time of this report, generally normal discharge had occurred in the Yukon River (Fig. 9). However, above normal runoff was apparent for the Nuyakuk River in summer 1977 because local rainfall added to the snowmelt discharge. Reports from field personnel indicate above normal rain, ground water tables, and lake levels in early 1978.

Aleutian Islands to Icy Bay

Flow along the south coast of Alaska and the Alaska Peninsula moves southwestward toward the Aleutian Islands where part of the flow moves northward into the Bering Sea, part continues westward along the Aleutian Chain, and the remainder turns southward and recirculates into the Gulf of Alaska.

Ice

Ice conditions in Prince William Sound and Cook Inlet were mild in both winters 1976-77 and 1977-78 and most bays were ice free by March of eacy year.

Temperature

Observations at coastal weather stations on the south coast of Alaska indicate that air temperatures were above normal in early 1977 and early 1978 but were near normal or below normal in mid and late 1977. Air temperatures were up to 3°C above normal at Cold Bay and Kodiak and 1° to 8°C above normal at Homer and Yakutat in January and February of both 1977 and 1978.

Sea surface temperatures[8] along the coast from the eastern Aleutians to Icy Bay (Fig. 10) normally range from minimum values of 3°-6°C in January to March to maximum values of 9°-14°C in August or September. Winter minima are lowest in the Kodiak Island and Alaska Peninsula areas while summer maxima are greatest off Prince William Sound and to the east.

Throughout the period January 1977 to March 1978 SST's (Fig. 11) were generally higher than normal along the entire coastline from the eastern Aleutian Islands to Icy Bay. Water temperatures 0.5° to 2.0°C higher than normal were common along the coast from Unimak Pass to Cook Inlet during the first half of 1977. During the second half of 1977 and early 1978 SST's returned to near normal although they continued mild. Water 1.0° to 2.4°C cooler than normal occurred off Prince William Sound and Cook Inlet during October 1977 to February 1978 but warmed to above normal in March 1978.

Generally both winters (1976-77 and 1977-78) were unusually warm. The mild winters and related high rainfalls have resulted in good survival of juvenile salmon as indicated by studies of preemergent fry. The warm conditions may advance the herring spawning by 1 or more weeks. Like the southeastern Bering Sea to the north across the Alaska Peninsula, the mild

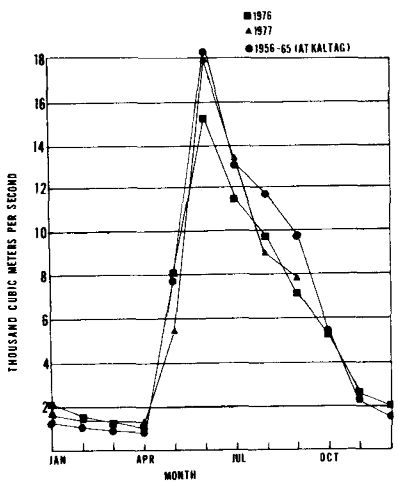


Figure 9.—Discharge of Yukon River at Pilot Station for 1976 and 1977 and 1956-65 long-term mean at Kaltag in thousands of cubic meters per second. Data from U.S. Geological Survey.

[5]Otto, R. S., J. E. Reeves, and J. Burns. 1977. King and Tanner crab research in the eastern Bering Sea, 1977. Unpubl. manuscr. Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, WA 98112.

[6]Favorite, F., T. Laevastu, and R. R. Straty. 1977. Oceanography of the northeastern Pacific Ocean and Bering Sea, and relations to various living marine resources. Processed report, 280 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, WA 98112.

[7]Seifert, R., and D. Kane. 1977. Effects of seasonability and variability of stream flow on nearshore coastal areas. Unpubl. manuscr. Inst. Water Resour., Univ. Alaska, Fairbanks, AK 99701.

[8]Averages of SST reports were made by 1° squares of latitude and longitude from observations made by passing ships and received by Fleet Numerical Weather Central. Maps of the original data are on file at Pacific Environmental Group, but for brevity only plots of SST by distance along the coast are included in this report. The long term mean values of SST are means for the period 1948-67 of SST observations in Tape Data Family-11, National Climatic Center, Environmental Data Service, NOAA, Asheville, NC 28801.

conditions which had begun in mid-1976 broke a 6-year run of below normal temperatures. This cold period was particularly serious in the Kodiak Island region where air temperature anomalies had been negative during 56 of the 69 months from August 1970 to April 1976 (anomalies were zero or positive in 11 months and data were missing in 2 months). Effects of cold weather had been severe on both salmon and pink shrimp in the Kodiak area.[9]

Runoff

Major rivers in this area and their annual mean discharge (100,000 meters per second) are: the Copper (2.4), Susitna (1.0), and Knik (0.7). Although a qualitative assessment of runoff indicates near normal conditions in 1977, total precipitation in Prince William Sound appeared to be below normal. Light snow pack occurred in 1978 and may result in low stream flows during the early salmon spawning season.

Salinity

Information on the distribution of surface salinity in Gulf of Alaska coastal waters during summer 1977 is available from a joint U.S.-Poland fishery oceanography survey conducted by the *Profesor Siedlecki* (Fig. 12). Immediately evident is the extensive dilution in the area of the Copper River. Another striking feature is the advection of water of less than 32‰ salinity over the continental slope at the head of the Gulf, well seaward of the inshore dilution caused by runoff from the Copper River. This apparent bifurcation of northwestward coastal flow, which has not been detected or reported before, may possibly influence the transport of ichthyoplankton, particularly halibut larvae, as well as the seaward migration path of salmon smolts from southeastern Alaska, British Columbia, Washington, and Oregon areas.

[9]Jerry McCrary, Regional Research Supervisor, Alaska Department of Fish and Game, Kodiak, AK 99615, pers. commun.

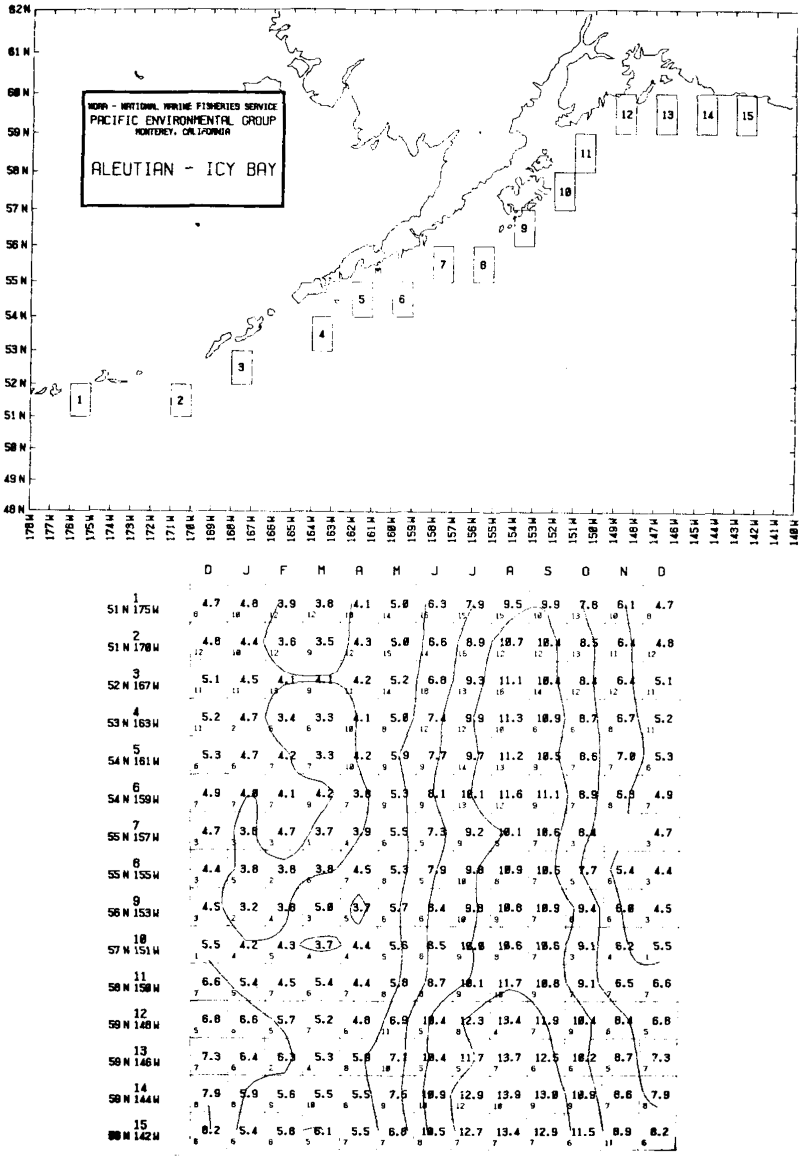


Figure 10.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Aleutian Islands to Icy Bay. Number of years of data available for each location is shown below SST value. Contour interval is 2.0°C.

Icy Bay to Strait of Juan De Fuca

The region of the northwest coast off southeastern Alaska and British Columbia is oceanographically the region where the West Wind Drift Current splits as it flows eastward toward the coast. Part flows north into the Gulf of Alaska and the remainder flows south as the California Current.

Temperature

Sea surface temperatures along the coast of southeastern Alaska and British Columbia follow somewhat the same trend as those to the westward described earlier (Fig. 13). Minimum temperatures of 4° to 7°C occur in March or April and maximum tempertures of 13° to 16°C occur in August.

During 1977 and early 1978, water temperatures off the northern portion of southeastern Alaska (Fig. 14) were similar to those to the west off Prince William Sound with warm water during January to July 1977 and generally cool water until February 1978. Off southern southeastern

	1977 J	F	M	A	M	J	J	A	S	O	N	D	1978 J	F	M
1 51 N 175 W	-1.0 2	-.1 3	0.2 5	0.1 5	1.0 10	-.6 5	1.0 5	0.8 2	-.2 10	-.4 5	-1.2 [illegible]	0.4 5	1.5 4	-.2 4	0.6 3
2 51 N 170 W	-2.2 [illegible]	-.4 4	0.5 1	-1.0 1		1.4 5	0.8 2	1.5 5	0.3 4		0.8 3			0.6 2	0.1 3
3 52 N 167 W	-.7 3	0.3 3	-.9 5	0.6 6	-.1 4	-.4 1	-.4 2	0.6 6	1.1 [illegible]	1.7 3	-.1 4	-.4 4		1.1 2	-.6 2
4 53 N 163 W	1.0 5	1.0 5	-.1 2	-.2 2	0.3 3	0.8 3	2.1 2	-1.3 1	1.1 8	0.2 10	-1.9 2	-.2 4	-.9 1	-.1 4	2.4 3
5 54 N 161 W	-1.0 3	0.7 9	1.0 10	0.1 12	0.8 16	1.8 5	1.4 4	0.8 7	1.1 70	1.2 48	-.5 18	-.3 9	0.2 13	0.6 10	0.9 22
6 54 N 159 W	0.7 9	0.9 6	-.2 46	0.4 14	1.3 11	1.1 8	3.3 7	0.9 7	-.1 7	0.6 22	-.2 27	-.4 15	0.6 13	-.1 14	-.0 21
7 55 N 157 W	1.0 136	0.6 154	0.6 35	-.1 1		1.8 5	0.7 7	1.6 3	-.2 3	0.9 42		-.9 4	2.1 1	-.8 6	0.7 8
8 55 N 155 W	1.4 2	1.3 8	0.7 11	-.1 4	0.9 3	1.9 3	2.0 7	0.2 1	0.9 6	1.2 12	0.8 7	1.0 6	-.0 5	0.7 47	1.7 2
9 56 N 153 W		2.3 2	0.0 6	1.6 4	0.8 4	1.8 7	1.3 9	1.0 7	1.2 4	-1.2 32	0.9 11	-.2 5	1.7 52	-.1 4	-.1 5
10 57 N 151 W		1.4 8	0.9 7	1.7 2	-.9 3	-.7 2	1.9 139	0.8 172	0.3 178	-.7 75	-.2 183	-.9 119	0.2 76	0.0 128	0.4 181
11 58 N 150 W	-.1 5	0.4 4	0.4 12	0.8 10	0.4 10	1.1 2	-1.0 4	1.5 8	0.4 9	0.7 18	0.8 11	-1.6 10	1.0 4	-.2 12	0.0 8
12 59 N 149 W	1.5 [illegible]	0.2 3	0.4 4		2.5 5	2.9 7	2.8 5	1.9 4	1.4 3	1.0 5	-.5 15		1.7 2	-1.6 3	
13 59 N 146 W			0.2 2			0.7 1		1.2 5	0.9 1	-1.3 1	-1.1 9	-1.6 2	-2.1 7		0.8 1
14 59 N 144 W	0.3 2		0.8 13	1.1 2		1.1 7	1.1 2	0.3 2		-1.4 1	0.5 3	-2.4 4	-1.0 3	-1.3 6	1.2 2
15 59 N 142 W	1.4 176	0.6 285	0.1 391	0.7 342	1.0 270	0.5 69	1.0 135	0.1 166	0.7 52	-.3 2	-.2 4		0.7 1		

Figure 11.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Aleutian Islands to Icy Bay for period January 1977 to March 1978. Squares are hatched for anomalies of +1.0°C or above and shaded for anomalies of -1.0°C or below.

Figure 12.—Surface salinity in parts per thousand, July 1977. Observations made by the research vessel *Profesor Siedlecki*.

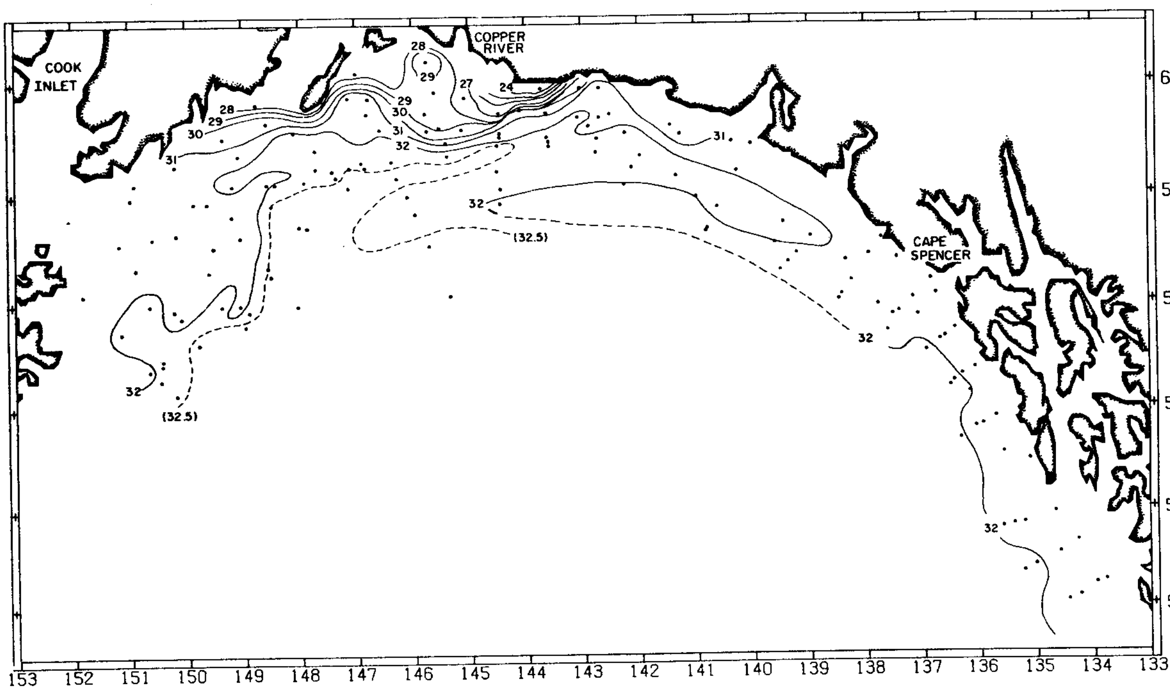


Table 1.—Representative winter sea surface temperatures (°C) at Sitka and Auke Bay, Alaska, 1976 to 1978.[1]

Area	Jan.	Feb.	Mar.	Remarks
Sitka				
1976	4.5	3.7	4.1	Cool
1977	6.4	6.1	5.7	Exceptionally warm
1978	4.2	4.6	4.8	Mild, warm
Auke Bay				
1976	2.6	2.6	2.4	Cold
1977	4.0	4.8	5.7	Exceptionally warm
1978	3.3	3.1	3.3	Mild, warm

[1]Based on data compiled by B. L. Wing, Northwest and Alaska Fisheries Center Auke Bay Laboratory, National Marine Fisheries Service, NOAA, Auke Bay, AK 99821.

Alaska and British Columbia, SST anomalies were more variable. Warmer than normal water occurred along the coast in January to March 1977 and again in March 1978. Cooler than normal water was prevalent off Vancouver Island during April to August.

Monthly mean coastal SSTs are available from coastal stations at Sitka and Auke Bay, Alaska, and indicate that winter conditions were 1.5° to 3°C warmer in 1977 than 1976 and up to 0.9°C warmer in 1978 than in 1976 (Table 1).

Data on SST fluctuations along the British Columbia coast are available from four lighthouse stations in exposed locations which make daily observations.[10] Monthly means of these data show that temperatures at all four stations during the first half of 1977 were 0.5° to 1.5°C warmer than normal with greatest positive anomalies off the northern British Columbia coast. During the second half of 1977 water temperatures were near normal. In early 1978 water temperatures again became warmer than normal (0.5° to 1.0°C above normal) with greatest positive anomalies off central British Columbia.

Scattered subsurface temperature measurements by expendable bathythermographs taken during the latter

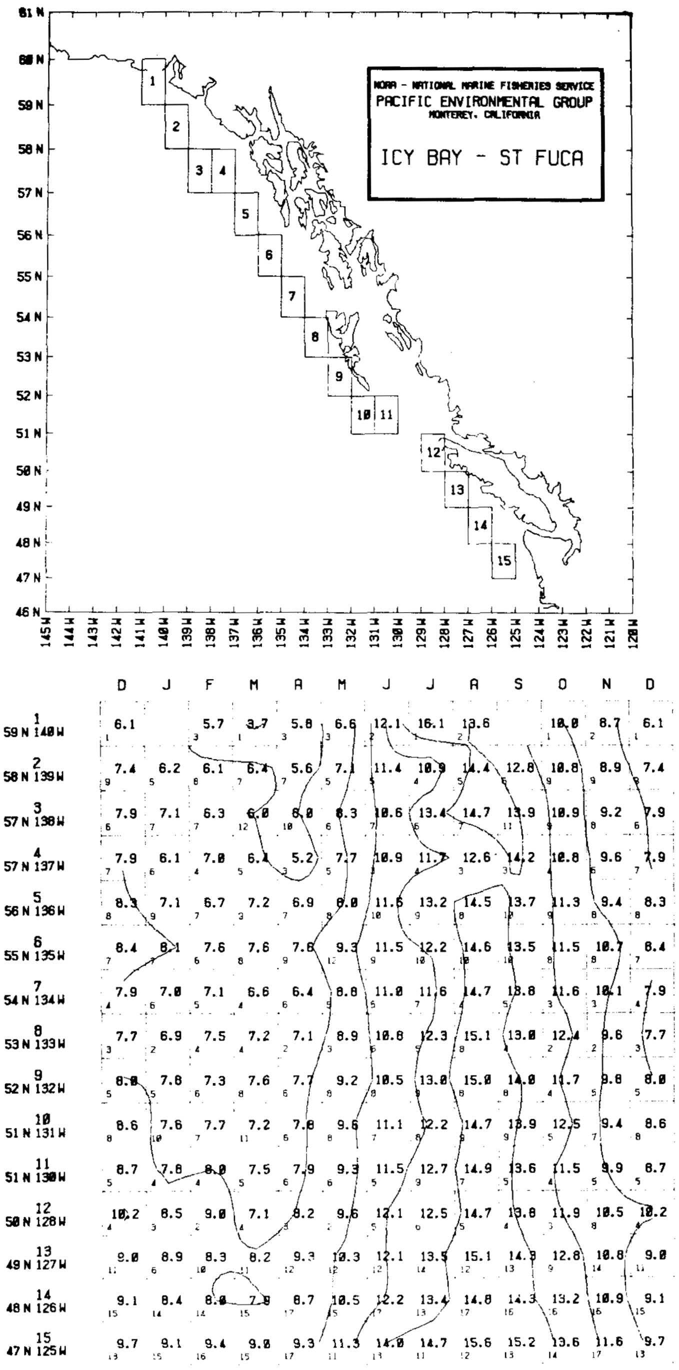


Figure 13.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Icy Bay to Strait of Juan de Fuca. Number of years of data available for each location shown below SST value. Contour interval is 2.0°C.

[10]Monthly means of daily surface temperature and salinity observations at Langara Island, Cape St. James, Kains Island, and Amphitrite Point were kindly furnished by L. F. Giovando, Pacific Environmental Institute, Environment Canada, West Vancouver, B.C. V7V 1N6.

part of March 1978 off the southern coast of Vancouver Island indicate the presence of anomalously warm water (9.5°-10°C) throughout the water column.[11]

Salinity

Measurements of surface salinity are also made daily at the British Columbia lighthouses (footnote 10). These data indicate that water salinities off the British Columbia coast were often 0.3 to 1.0‰ above normal during 1977. Data from early 1978 are available for only one station (Langara Island) and they indicate that salinities were 0.5 to 1.0‰ below normal.

Strait of Juan De Fuca to Gulf of California

Off the west coast of the United States, relatively cool and low salinity waters are transported southward by the California Current. The Current contains meandering streams of flow and eddies but in long term averages the Current appears as a slow, broad flow. These waters are separated from the warmer, more saline North Pacific Central waters to the west by the Transition Zone—a region of ocean fronts. The northward flowing California Undercurrent lies inshore of the California Current, immediately adjacent to the coast and is seasonally variable. From Oregon southward to Baja California, prevailing northwest winds in summer cause upwelling of deeper, nutrient rich waters which support biological productivity. Ingraham and Love (1978) presented detailed observations of water temperature, salinity, and concentration of dissolved oxygen made in the summer of 1977 over the continental shelf along the coast by the Polish research vessel *Profesor Seidlecki*. The data show many details of the spatial distribution of properties but, unfortunately, comparable data are not available for other years.

[11]A. J. Dodimead, Pacific Environmental Institute, Environment Canada, West Vancouver, B.C. V7V 1N6, pers. commun.

	1977 J	F	M	A	M	J	J	A	S	O	N	D	1978 J	F	M
1 59 N 140 W			0.6 (14)	2.1 (2)	2.4 (1)	1.0 (1)						2.9 (1)			
2 58 N 139 W	0.8 (3)		0.2 (4)			1.4 (8)		-1.4 (1)			-.2 (5)		-.5 (7)		
3 57 N 138 W	-.3 (3)	1.7 (2)	0.3 (2)	0.7 (1)	0.0 (1)		-.1 (3)	-1.7 (1)	-.9 (3)	2.1 (2)	-.3 (1)		-1.0 (1)	-1.9 (1)	1.0 (1)
4 57 N 137 W	0.5 (5)					0.9 (2)		2.2 (1)		-.8 (1)		-2.3 (1)	-.2 (3)		
5 56 N 136 W	-.1 (3)	1.2 (1)	0.0 (1)	0.4 (1)	-.2 (1)	-.6 (1)	-1.1 (4)	-1.6 (3)	-1.7 (2)		-1.0 (3)	-2.2 (1)		-.5 (2)	
6 55 N 135 W	-1.0 (1)		-1.4 (2)	-2.6 (2)		-.5 (3)	-.3 (3)	-1.6 (1)	-.1 (2)		-2.7 (1)		-.9 (1)	-.5 (2)	
7 54 N 134 W	0.4 (3)	1.0 (2)	1.2 (1)			-.9 (2)	0.9 (1)		0.4 (2)				1.9 (1)	0.1 (4)	-.2 (3)
8 53 N 133 W	1.1 (1)		0.8 (2)	0.2 (7)	-.7 (1)	0.8 (3)	1.5 (2)	-2.4 (4)	2.2 (3)	0.6 (3)	-.2 (2)	-.2 (2)	2.1 (1)	-.3 (3)	-.7 (3)
9 52 N 132 W	0.5 (4)	0.4 (4)	-1.1 (3)	0.3 (7)	-.8 (8)	1.7 (1)	-1.3 (1)	-.2 (3)	0.3 (9)	0.5 (5)	1.3 (2)	-.4 (7)	-1.0 (8)	-.4 (12)	-.1 (4)
10 51 N 131 W	0.6 (7)	1.5 (8)	-.3 (8)	-.1 (7)	-.7 (6)	-.4 (5)	-.8 (3)	-.4 (10)	0.6 (3)	-.4 (9)	-.4 (15)	-1.1 (9)	0.9 (3)	-1.0 (2)	1.0 (11)
11 51 N 130 W	-.9 (6)	0.3 (1)	1.0 (4)	-1.7 (5)	-.1 (15)	-.0 (7)	0.5 (8)	0.0 (5)	0.6 (10)	0.4 (11)	0.1 (7)	-.6 (8)	1.0 (3)	0.8 (11)	1.7 (3)
12 50 N 128 W	-.0 (6)	0.5 (3)	1.2 (15)	-.8 (14)	0.0 (9)	-1.4 (7)	-.3 (3)	-1.2 (3)	1.1 (6)	0.2 (6)	-.6 (4)	-2.8 (4)	0.2 (6)	-.8 (7)	1.8 (5)
13 49 N 127 W	-.6 (5)	-.2 (11)	-.2 (11)	-.8 (21)	0.4 (18)	-.7 (14)	-.8 (5)	-.7 (9)	-1.5 (15)	-1.0 (10)	0.2 (11)	-1.1 (10)	-.1 (13)	0.3 (11)	1.0 (5)
14 48 N 126 W	1.1 (3)	2.4 (3)	0.2 (10)	-.3 (8)	-.1 (27)	-.7 (10)	-.1 (8)	-1.6 (5)	-1.8 (49)	-.8 (12)	-.4 (9)	0.1 (4)	1.1 (8)	-.2 (4)	0.8 (18)
15 47 N 125 W	-2.0 (5)	1.3 (9)	0.7 (13)	-.1 (5)	1.5 (7)	-2.4 (9)	1.0 (4)	-.6 (6)	-.0 (3)	6.2 (11)	-.5 (2)		-1.4 (3)	0.1 (10)	0.4 (5)

Figure 14.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Icy Bay to Strait of Juan de Fuca for period January 1977 to March 1978. Squares are hatched for anomalies of +1°C or above and shaded for anomalies of -1°C or below.

California Current and Transition Zone

The structure of the California Current and Transition Zone[12] regions has been monitored routinely since 1966 by merchant ships operating between San Francisco and Honolulu. These ships make observations of surface and subsurface temperature and surface salinity at about 120-km intervals along the track on a twice monthly schedule. Along the ship transit lane the surface water temperatures and salinities had been near normal during the winter of 1975-76 (Saur, 1978). During the winter of 1976-77 the salinities were 0.2 to 0.5‰ lower than the previous winter between long. 129° and 146°W and surface temperatures were similar to those of the previous winter (Saur and McLain, In press). During the winter of 1977-78 salinities in the same region were lower yet, 0.4-0.5‰ below average, while the corresponding temperatures had decreased on the order of 1.5°C. One possible explanation for these observations is that there was a significant increase in the advection of cool, low-salinity subarctic waters southward and into the California Current. Computations of Ekman transport (Fig. 4) suggest an increase in the West Wind Drift Current in both winters. Another possible cause is a significant increase in precipitation. During these winters

[12]Material for this section was developed by J. F. T. Saur, Scripps Institution of Oceanography, La Jolla, CA 92038.

there were large regions of increased southerly winds, indicative of storms and the transport of tropical, high humidity air northward. While both factors (increased advection and precipitation) were likely operative, there were some important differences in each year. During the winter of 1976-77 the winds with an anomalous southern component occurred west of long. 130° W (Fig. 2, lower). Excess local precipitation was then probably a principal cause of the observed low salinities as there is not the requisite time lag for advection to significantly alter the salinity. In the following winter (1977-78) the anomalous southern wind component occurred nearer the coast (east of long. 135°-140° W, Fig. 3, lower) where records of low salinity and high rainfall suggest excess precipitation. Farther offshore the decrease in temperature and salinity suggest that increased advection from more northerly sources was important.

The spring and early summer migration of albacore into the U.S. west coast fishery has been shown to be associated with the Transition Zone and with individual fronts within it (Laurs and Lynn, 1977). The Transition Zone is bounded by strong horizontal gradients of temperature and salinity, the subarctic and subtropic ocean fronts. The degree of development of these ocean fronts appears to affect the path of migration of albacore, their aggregation in offshore areas, and perhaps the timing of their movement into traditional nearshore fishing grounds.

Surveys of the oceanographic character of the fronts have been made annually in recent years. Such a survey was made in June 1977[13] in the region of the Transition Zone through which the albacore migrate shoreward. The survey found only remnants of the ocean fronts where in other years there had been clearly defined features. Drifter buoys were deployed in the region (lat. 33° N, long. 137° W) and monitored daily in subsequent months. While the drifting buoys retained their drogues, they moved in circuitous paths. The buoy tracks and the lack of frontal development suggest considerable ocean surface mixing.

The structure of the ocean fronts in the Transition Zone as observed from the merchant ships between San Francisco and Honolulu has been published monthly in *Fishing Information* (footnote 4) since 1972. In March 1977 there appeared to be a well defined subtropic front. In the following months a broad region of temperature inversions occurred without a strong subtropic front. This may be indicative of the mixing found by the June oceanographic survey. In September and October the subtropic front reappeared and was strongly developed. (The surface salinity, which is important in the identification of ocean fronts, was unfortunately not available for many of the transects.) By March 1978 a typical situation prevailed; both fronts were of average intensity.

Temperature

As was noted for the British Columbia coast, sea surface temperatures off Washington and Oregon (Fig. 15) are minimum in March and maximum in August. Off southern Oregon and northern California the normal seasonal warming in summer is depressed by upwelling of cold waters and summer mean temperatures do not reach 14° C, whereas 15°C temperatures are observed to both the north and south. Off central California seasonal heating again becomes dominant and surface temperatures reach summer maxima of over 16° C. The peaks are delayed a month or so, however, from those to the north with minima occurring in March or April and maxima in September.

During January and February 1977 SST's off the west coast (Fig. 16) were generally above normal (up to +2°C anomalies). A strong pulse of upwelling in March (Fig. 5) caused anomalous cooling and by April SST's were below normal along almost the entire stretch of coast with anomalies more negative than -1.0° C off central California. In May upwelling was weak and SST's rose anomalously. In June, upwelling increased again and temperatures were again below normal. Except for an area of warmer than normal water off northern California in August, SST's remained below normal through November while upwelling remained strong. Temperatures in December were generally above normal. During January through March 1978 water temperatures were consistently above normal (with anomalies of over +2.0° C common) along almost the entire stretch of coast in association with very weak upwelling and, in some instances, downwelling.

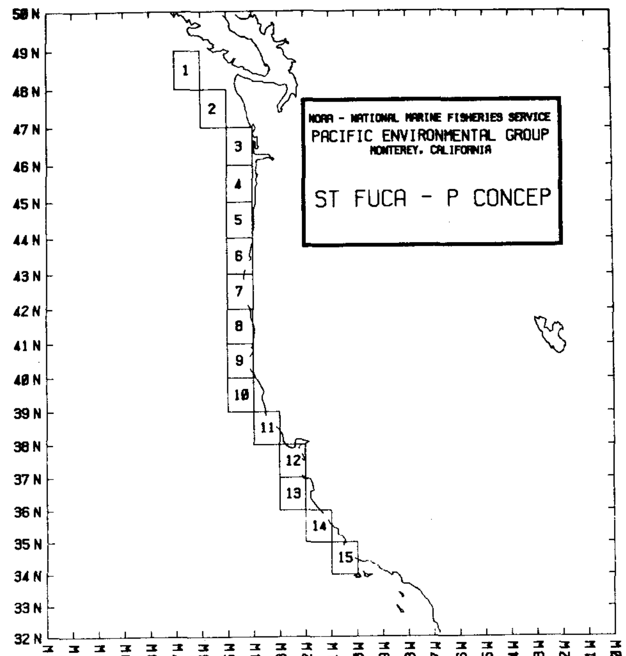
Sea surface temperatures from Point Conception southward to the Gulf of California (Fig. 17) show a regular seasonal warming and cooling cycle with minima in March to May and maxima in August or September. During January and February 1977 SST's along the coast (Fig. 18) were almost uniformly 1.5° to 2.5°C above normal as a result of calm, clear weather under the persistent high pressure system which prevailed along the coast. Due to the strong upwelling pulse in March, SST's returned to near normal values and remained near normal through July. A pulse of upwelling in August reduced SST's to below normal but conditions returned to near normal in September and October. Anomalous warming began in October and November and by December SST's were again almost uniformly above normal. Warmer than normal temperatures persisted through March 1978 when anomalies above +2° C were common off northern Baja California in March in association with weak upwelling.

Upwelling

Bakun and Parrish[14] have recomputed the indices of intensity of coastal

[13]Lynn, R. J. Unpublished cruise report, Cruise 111, RV *David Starr Jordan*, Southwest Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.

[14]Reported in the Monthly Report for March 1978, Southwest Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.



	D	J	F	M	A	M	J	J	A	S	O	N	D
1 48 N 126 W	9.1 15	8.4 14	8.0 14	7.8 15	8.7 17	10.5 15	12.2 17	13.4 13	14.8 17	14.3 16	13.2 16	10.9 16	9.1 15
2 47 N 125 W	9.7 13	9.1 15	9.4 16	9.0 15	9.3 17	11.3 11	14.0 13	14.7 11	15.6 12	15.2 13	13.6 14	11.6 17	9.7 13
3 46 N 124 W	10.3 9	9.7 9	9.2 14	9.0 15	10.0 14	11.9 13	13.8 14	15.0 14	15.7 14	15.4 14	13.5 13	12.0 15	10.3 9
4 45 N 124 W	10.8 12	9.9 14	9.6 13	9.5 18	10.2 16	11.8 17	13.9 16	14.8 13	15.8 17	15.3 17	13.9 14	12.0 16	10.8 12
5 44 N 124 W	11.1 17	10.2 13	9.9 18	9.7 18	10.2 17	11.2 16	13.6 16	14.0 14	14.5 15	14.6 14	14.0 17	12.1 14	11.1 17
6 43 N 124 W	11.1 16	10.6 15	10.1 14	9.8 17	10.5 18	11.5 16	13.0 16	13.1 15	13.8 12	14.0 18	13.3 13	12.1 16	11.1 16
7 42 N 124 W	11.7 17	10.5 14	10.5 15	10.5 18	10.4 17	11.4 17	11.9 16	11.8 16	12.6 14	13.3 18	13.1 17	12.6 16	11.7 17
8 41 N 124 W	11.9 17	11.0 15	10.7 16	10.6 18	10.6 17	11.3 18	12.1 18	11.9 16	12.3 16	13.0 18	12.8 16	12.2 17	11.9 17
9 40 N 124 W	12.3 17	11.1 15	10.8 16	10.8 18	10.8 17	11.8 18	11.8 18	12.0 17	12.7 14	13.2 17	13.2 17	12.6 18	12.3 17
10 39 N 124 W	12.7 19	11.5 20	11.4 18	11.1 20	10.7 20	11.6 20	12.1 20	12.6 20	12.9 20	13.7 19	13.5 19	13.3 20	12.7 19
11 38 N 123 W	12.8 19	11.6 19	11.6 19	11.4 20	11.3 20	11.6 20	12.0 20	12.6 19	13.5 20	13.7 18	14.0 20	13.5 20	12.8 19
12 37 N 122 W	12.7 19	12.2 19	12.3 18	12.2 20	12.1 18	12.7 19	13.6 20	14.2 19	14.6 20	15.8 20	15.2 19	14.0 20	12.7 19
13 36 N 122 W	13.7 19	12.8 20	12.4 19	12.3 20	12.4 20	12.7 20	13.5 20	14.3 20	14.6 20	15.6 20	15.1 19	14.3 20	13.7 19
14 35 N 121 W	13.9 20	12.9 20	12.9 20	12.7 20	12.5 20	12.5 20	13.5 20	14.3 20	14.9 20	15.6 20	15.5 20	14.8 20	13.9 20
15 34 N 120 W	14.4 19	13.6 20	13.4 19	12.9 20	12.9 19	13.2 20	14.0 20	15.5 20	16.1 17	16.6 20	16.1 20	15.4 20	14.4 19

Figure 15.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Strait of Juan de Fuca to Point Conception. Number of years of data available for each location shown below SST value. Contour interval is 2.0°C.

upwelling, described earlier, at 6-hourly intervals for the winters of 1976-77 and 1977-78. They showed that the patterns of upwelling were very different during the two periods. Off California the relatively strong upwelling in the winter of 1976-77 was a relaxed, low-energy situation under the persistent high pressure system that prevailed over California at that time. In contrast the winter of 1977-78 was marked by intense, highly fluctuating upwelling and downwelling episodes as storms moved onto the coast. In monthly averages these episodes appeared as weak upwelling (or downwelling).

The biological effects of these two patterns of upwelling would be quite different. The slack conditions from November to February of 1976-77 should have subjected organisms to less than normal levels of onshore and offshore excursions of surface waters, to reduced turbulent mixing, and to reduced dispersion of planktonic aggregations. During 1977-78, however, strong pulses of wind caused onshore-offshore excursions which should have caused strong turbulent mixing, destroying patch structure of plankton. Smith and Lasker (1978) suggested that changes in concentrations of plankton due to upwelling changes may be an important factor in survival of larval anchovies.

Runoff

The Columbia River, whose seaward discharge is second only to the Yukon River, and the accumulated flow from the Fraser River and the Puget Sound Basin that discharges through the Strait of Juan de Fuca, are nearly equivalent. However, mixing and stirring processes in the Strait diminish the salinity differences between inshore and coastal waters, whereas marked salinity gradients occur at the edges of the Columbia River plume. Columbia River runoff data for January to September 1977 (Fig. 19) indicate a 50 percent reduction from the same period in 1976, reflecting the west coast drought. Perhaps more significant is the absence of a peak discharge in May or June

1977. During this annual, critical runoff period, flow was only a third of normal conditions and half those of 1976. The absence of this annual pulse of freshwater could have a variety of effects on salmon in the river and on coastal marine organisms.

Salinity

Lower than normal surface salinities were observed by the merchant ships in the California Current between San Francisco and Honolulu as has been mentioned. Low salinities were also observed on research cruises of the California Cooperative Oceanic Fisheries Investigations in early 1978. The cruises covered roughly the area within 450 km of the coastline from central California to Baja California. The series of surveys, in December 1977 and January, March, and April 1978, revealed an increasing and expanding salt deficit in the surface layer. The freshened waters are attributed to unusually high local precipitation which reflected the heavy rains observed at coastal stations. The excess rainfall, computed as that amount of freshwater required to produce the salinity anomaly, was approximately 0.5 to 1 m over the 5 months, December 1977—April 1978. This amount is twice the excess rainfall recorded at San Diego (0.22 m) and Santa Barbara (0.57 m) for the same period and 2-3 times the estimated annual average rainfall. The anomalously low salinities extended well into the pycnocline. The low salinity values at depth may be due to increased advection of low salinity water from the north.

	1977												1978		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 48 N 126 W	1.1 (9)	2.4 (8)	0.2 (10)	-.3 (8)	-.1 (27)	-.7 (10)	-.1 (8)	-1.0 (5)	-1.0 (49)	-.8 (12)	-.4 (9)	0.1 (4)	1.1 (8)	-.2 (4)	0.8 (18)
2 47 N 125 W	-2.0 (5)	1.3 (9)	0.7 (13)	-.1 (5)	1.5 (7)	-2.4 (9)	1.0 (4)	-.6 (8)	-.0 (3)	0.2 (11)	-.5 (2)		-1.4 (3)	0.1 (10)	0.4 (5)
3 46 N 124 W	-.9 (190)	0.1 (173)	0.2 (223)	-.1 (189)	-.4 (21)	-.6 (12)	-2.0 (119)	-2.0 (183)	-.8 (246)	0.9 (261)	0.2 (241)	-.3 (245)	0.2 (220)	0.6 (241)	0.6 (253)
4 45 N 124 W	1.1 (11)	0.2 (7)	0.7 (15)	-.2 (5)	0.2 (9)	-.6 (131)	0.0 (36)	-.3 (28)	-1.0 (88)	-.5 (31)	-.9 (8)	1.0 (6)	1.2 (6)	0.9 (9)	1.4 (5)
5 44 N 124 W	-.2 (6)	1.3 (4)	0.6 (6)	0.6 (5)	1.7 (13)	-1.1 (200)	-.7 (77)	-.6 (346)	-.4 (395)	0.2 (130)	-1.0 (6)	-.5 (4)	1.1 (5)	1.8 (12)	2.5 (7)
6 43 N 124 W	0.0 (6)	0.6 (6)	0.1 (9)	-.4 (9)	0.8 (21)	-.6 (79)	0.1 (52)	-.9 (383)	0.2 (400)	0.8 (146)	-.6 (7)		1.3 (4)	1.5 (15)	1.9 (8)
7 42 N 124 W	1.4 (8)	1.4 (7)	0.1 (11)	-.2 (7)	1.6 (17)	-.1 (36)	0.8 (159)	0.1 (125)	-.2 (30)	-.1 (14)	0.4 (9)	0.4 (4)	1.5 (3)	2.0 (8)	1.2 (6)
8 41 N 124 W	-.2 (5)	1.6 (10)	0.7 (15)	-.5 (14)	0.8 (17)	0.4 (26)	0.5 (268)	1.2 (45)	0.6 (30)	-.4 (6)	-.1 (11)	-.7 (7)	0.5 (4)	0.7 (11)	2.0 (7)
9 40 N 124 W	0.8 (11)	0.5 (8)	0.2 (15)	-.5 (15)	0.2 (16)	-.7 (14)	0.7 (123)	1.1 (34)	-.3 (19)	0.2 (9)	-.0 (7)	1.1 (2)	1.0 (6)	2.0 (13)	1.5 (7)
10 39 N 124 W	0.9 (12)	0.7 (21)	0.1 (18)	-.6 (14)	-.2 (24)	-1.1 (15)	0.1 (11)	1.3 (15)	-.4 (25)	-.4 (11)	-.8 (12)	0.4 (6)	0.7 (11)	0.8 (20)	1.6 (10)
11 38 N 123 W	0.7 (10)	1.1 (12)	0.6 (10)	-.9 (11)	1.5 (14)	-1.7 (11)	-1.0 (11)	-.7 (8)	-.2 (11)	-.4 (8)	-.4 (7)	0.4 (10)	1.3 (6)	1.3 (9)	1.5 (8)
12 37 N 122 W	1.4 (6)	1.4 (6)	-.1 (18)	-1.0 (1)	-.3 (9)	-.6 (8)	-2.0 (6)	0.7 (5)	-1.4 (6)		0.8 (5)	1.0 (9)	2.1 (4)	1.2 (12)	0.2 (4)
13 36 N 122 W	1.1 (6)	1.0 (11)	-.6 (20)	-1.4 (12)	0.7 (14)	-.5 (8)	-1.9 (6)	-.2 (7)	0.1 (16)	-.2 (17)	-1.1 (10)	-.9 (10)	0.8 (12)	1.7 (25)	0.9 (12)
14 35 N 121 W	1.3 (12)	1.8 (13)	-.5 (21)	-1.4 (12)	0.1 (15)	-1.3 (10)	0.1 (19)	-.4 (7)	2.6 (12)	0.1 (12)	-1.1 (11)	1.0 (9)	0.8 (12)	1.0 (17)	1.5 (17)
15 34 N 120 W	2.0 (9)	1.7 (13)	-.1 (13)	-1.0 (11)	-.6 (11)	-1.5 (4)	0.8 (12)	-2.5 (7)	0.9 (11)	0.1 (13)	-.8 (7)	0.5 (7)	2.7 (3)	0.8 (10)	1.5 (13)

Figure 16.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Strait of Juan de Fuca to Point Conception for the period January 1977 to March 1978. Squares are hatched for anomalies of °C or above and shaded for anomalies of -1°C or below.

Eastern Tropical Pacific Conditions

Oceanographic conditions in the eastern tropical Pacific (ETP) are influenced by the Equatorial current systems and their variations.[15] The trade winds of the equatorial regions drive the westward flowing North and South Equatorial Currents.

The North and South Equatorial Countercurrents flow eastward. Variations in these currents occur and major changes, known as El Niño events, transport unusually large amounts of warm, saline waters towards the coast. Such events are related to fluctuations in the strength and position of the trade winds over large areas of the tropical Pacific. Quinn (1976, 1978, in press) has described relations of El Niño conditions in the ETP to the Southern Oscillation—a variation of atmospheric pressure across the tropical Pacific Ocean. Upwelling occurs off the west coasts of Peru and Ecuador and along a broad band westward along the Equator as a result of divergence caused by the trade winds. Upwelling is strongest during August and September.

Variations in oceanographic conditions in the ETP affect the fishery resources of the area in various ways. A major El Niño event occurred in 1972 and was followed by a serious decline in production of anchoveta off Peru. The exact mechanism of the decline is still in question but it no doubt involved a combination of heavy fishing pressure and environmental change. Tunas are mobile, highly migratory animals and are related to their environment in complex ways. Changes in the distribution and availability of tunas are related to variations in SST, thermocline depth, and other oceanographic conditions while variations in skipjack tuna

[15]Much of the material of this section was prepared by Forrest Miller, Inter-American Tropical Tuna Commission, La Jolla, CA 92037. It is based on material developed for *Fishing Information* and the reader is referred to that publication for charts of monthly sea surface temperature (SST) and anomaly of SST from a long-term mean.

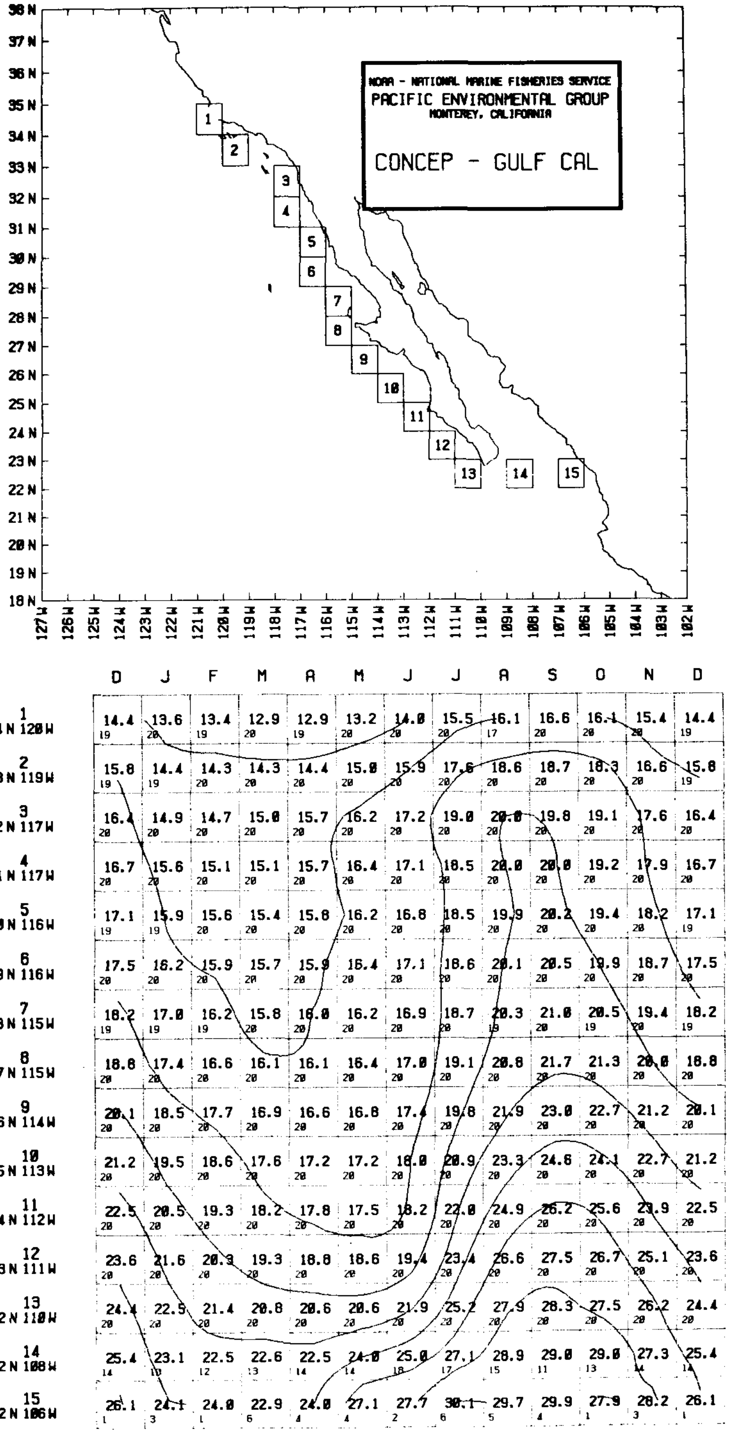


Figure 17.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Point Conception to Gulf of California. Number of years of data available for each location shown below SST value. Contour interval is 2.0°C.

abundance have been correlated with the Southern Oscillation.

Sea Surface Temperature

Fluctuations of oceanographic conditions in the ETP are commonly monitored from patterns of SST. Such patterns can be characterized as complex patterns of ocean fronts bordering on large warm and cool water areas. Fairly regular seasonal changes occur in the locations and intensities of these frontal boundaries and associated SST patterns. The seasonal pattern is modified in El Niño years when SST's are unusually high over most of the ETP and ocean fronts along the Equator are weak. Frequently, during 1 or more years preceding an El Niño, SST's are abnormally low over large areas of the tropics, especially along the Equator as a result of strong trade winds and strong equatorial upwelling.

A moderately intense El Niño had occurred in 1976 (Quinn, in press) with associated positive SST anomalies reaching a maximum in December 1976. During January to March 1977 (Fig. 20), SST's remained above normal over most of the ETP. As was seen in Figure 18, SST's along the coast of Baja California were more than 1°C above normal. Along the southwest coast of Central America and over most of the ETP north of lat. 5°N, SST's were within 0.5°C of normal. Along the Equator east of long. 150°W and off Peru, there were several areas where SST's were more than 1°C above normal from the warming during the 1976 El Niño although these areas diminished rapidly in size during January. The Gulfs of Tehuantepec and Panama and waters off the south coast of Peru (south of lat. 15°S) all experienced SST's which were more than 1°C below normal during the first quarter due to strong wind mixing.

During April to June a distinct shift from warm to cool conditions took place over most of the coastal areas off the west coasts of Mexico (Fig. 18) and also off Central and South America with SST's reaching as much as 1°C below normal off Ecuador. Along the Equator from lat. 5°N to 5°S upwelling reduced SST's to 0.5° to 1°C below normal in April. During May the area of negative SST anomalies (more than 1°C below normal) expanded westward from the Galapagos Islands-Ecuador region. This pattern of SST anomalies—below normal temperatures off Central and South America and along the Equator and near normal temperatures elsewhere in the ETP—persisted through October. Maximum negative anomalies (as much as -1.5°C below normal) due to upwelling along the Equator occurred in September. During 1977 the Southern Hemisphere subtropical high pressure system (normally centered near lat. 30°S, long. 90°W) was not in its normal position and surface pressures were frequently below normal. As a result, the southeast trade winds and upwelling were weaker than normal along the coast of South America and over the equatorial central Pacific.

During July to December, SST's in the Northern Hemisphere and west of long. 120°W warmed faster than normal and the eastern part of the ETP north of the Equator warmed more slowly than normal. Negative anomalies along the Central American coast (east of long. 100°W and north of lat. 5°N) occurred during this period and were associated with increases in tropical storm activity which increased markedly in July. A band of negative SST anomalies offshore of the coast of Central America and Mexico occurred in areas of heavy wind mixing in the paths of tropical storms which developed from July to October 1977.

Apart from seasonal changes the SST anomalies during October to December did not markedly change from earlier conditions. Tropical storm activity in the ETP from Costa Rica to Baja California continued through October leaving a broad zone of deeply mixed tropical water and scattered areas with negative anomalies (greater than 1°C below normal) where storms intensified most often. West of long. 120°W and south of lat. 20°N SST's were more than 1°C above normal due to below normal cloud cover and light trade winds. By November the areas of large positive anomalies were reduced

	1977 J	F	M	A	M	J	J	A	S	O	N	D	1978 J	F	M
1 34 N 120 W	2.0 (9)	1.7 (15)	-.1 (13)	-1.0 (11)	-.6 (11)	-1.5 (4)	0.8 (12)	-2.5 (7)	0.9 (11)	0.1 (13)	-.8 (7)	0.5 (7)	2.7 (3)	0.8 (10)	1.5 (18)
2 33 N 119 W	0.3 (4)	1.2 (7)	0.3 (17)	-.6 (7)	0.5 (4)	-.5 (7)	-1.0 (7)	-.3 (13)	0.3 (4)	-.2 (3)	0.6 (7)	-.3 (8)	1.2 (8)	1.7 (9)	1.3 (11)
3 32 N 117 W	2.2 (14)	2.3 (4)	1.4 (11)	0.7 (28)	0.2 (20)	0.2 (51)	0.3 (15)	-.1 (12)	0.1 (13)	1.1 (18)	1.0 (27)	1.6 (10)	1.7 (5)	0.4 (12)	2.5 (19)
4 31 N 117 W	1.3 (19)	1.9 (9)	1.1 (7)	0.3 (23)	0.4 (10)	0.2 (8)	0.1 (4)	0.2 (14)	0.5 (18)	1.4 (12)	2.2 (9)	1.2 (16)	0.8 (8)	1.5 (18)	2.4 (6)
5 30 N 116 W	2.2 (6)	2.4 (6)	-.0 (17)	-.5 (26)	-.2 (11)	0.2 (9)	0.7 (2)	-.1 (13)	-.1 (23)	-.1 (23)	1.0 (12)	1.5 (12)	1.6 (5)	1.2 (9)	2.2 (15)
6 29 N 116 W	2.1 (24)	0.6 (15)	1.1 (24)	0.5 (27)	0.5 (14)	-.5 (13)	1.5 (7)	-.2 (6)	0.6 (22)	-.1 (15)	0.1 (12)	2.2 (21)	2.3 (14)	2.1 (20)	2.3 (16)
7 28 N 115 W	2.4 (7)	2.3 (7)	1.4 (12)	0.1 (15)	0.4 (7)	0.0 (16)	0.8 (3)	-.3 (7)	0.8 (10)	0.3 (21)	0.7 (13)	2.2 (15)	1.9 (15)	1.7 (11)	2.3 (11)
8 27 N 115 W	2.0 (12)	1.5 (14)	1.8 (23)	0.1 (24)	0.8 (20)	0.9 (16)	0.3 (4)	-.5 (11)	0.7 (18)	-.0 (26)	1.3 (26)	1.2 (14)	1.3 (14)	1.9 (10)	2.3 (17)
9 26 N 114 W	1.5 (20)	1.5 (10)	1.1 (16)	0.4 (22)	0.3 (20)	0.4 (29)	0.5 (16)	-.5 (15)	0.0 (25)	1.0 (15)	1.3 (22)	1.7 (25)	1.8 (20)	0.7 (13)	1.9 (16)
10 25 N 113 W	1.0 (12)	1.5 (13)	0.8 (19)	0.3 (23)	0.8 (20)	0.4 (22)	0.3 (9)	0.1 (19)	-.2 (18)	0.5 (18)	0.2 (14)	1.1 (21)	1.3 (14)	1.1 (24)	1.5 (16)
11 24 N 112 W	1.0 (14)	0.8 (11)	1.5 (13)	1.0 (21)	0.4 (18)	0.6 (17)	-1.0 (8)	-.3 (9)	-.3 (17)	0.1 (21)	1.4 (21)	0.6 (13)	1.4 (14)	0.5 (10)	1.7 (12)
12 23 N 111 W	1.2 (17)	1.4 (14)	2.7 (17)	2.0 (23)	0.3 (8)	1.8 (18)	0.1 (13)	-.9 (12)	0.1 (23)	0.8 (16)	0.7 (10)	0.7 (12)	2.1 (19)	1.3 (14)	0.3 (10)
13 22 N 110 W	1.0 (10)	1.5 (7)	1.1 (15)	0.2 (19)	1.0 (7)	-.2 (14)	-.5 (8)	-1.6 (19)	-.1 (23)	0.7 (21)	0.8 (23)	1.0 (11)	2.0 (12)	1.0 (14)	0.6 (11)
14 22 N 108 W	1.6 (7)		1.6 (5)	1.9 (5)	0.8 (3)	-3.0 (8)		-2.2 (1)	1.3 (3)	0.4 (3)	0.6 (1)	2.6 (4)	2.4 (3)	1.5 (2)	-.6 (1)
15 22 N 106 W			-2.1 (1)		-1.1 (2)				1.1 (2)	2.4 (4)	0.8 (2)	1.3 (4)		0.0 (1)	

Figure 18.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Point Conception to Gulf of California for period January 1977 to March 1978. Squares are hatched for anomalies of +1°C or above and shaded for anomalies of -1°C or below.

in size. In the Southern Hemisphere SST's remained slightly above normal with scattered areas of positive anomalies greater than 1°C until the end of the year. However, by December SST's in the area west of long. 85°W from lat. 5° to 30°S, which had been above normal since May 1975, were beginning to return to normal. Along the coast of South America and along the Equator (lat. 5°N to 5°S), SST's were, on an average, slightly below normal most of the time with an occasional positive anomaly extending into the equatorial region from the trade wind zones of both hemispheres.

During January 1978 temperatures throughout the ETP were near normal with the exceptions of warmer than normal water off Baja California due to the weak upwelling there and cooler than normal water off Peru and west of

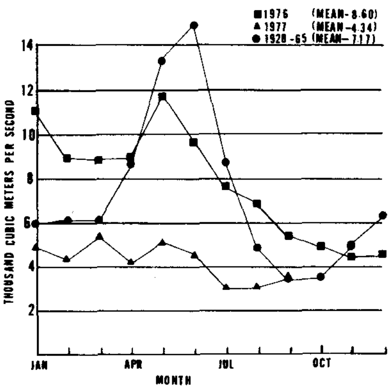


Figure 19.—Discharge of Columbia River near Astoria for 1976 and 1977 and 1928-65 long-term mean in thousands of cubic meters per second. Data from U.S. Geological Survey.

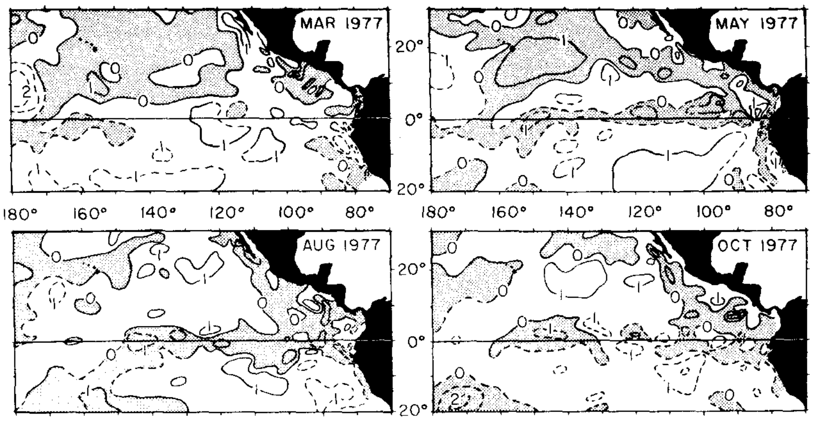


Figure 20.—Departure of sea surface temperature (in °C) from long term monthly averages in the eastern tropical Pacific Ocean for 4 months of 1977. Shaded areas are below average. (Adapted from *Fishing Information*.)

the Galapagos Islands due to strong upwelling. Below normal water temperatures continued to occur in the Gulfs of Tehuantepec and Panama due to wind mixing. This pattern continued during February and March although the cooler than normal water west of the Galapagos Islands was not present in March.

Tuna Fishing Conditions

From January through April 1977 the catches of yellowfin tuna east of long. 100°W were the lowest for that period in 18 years. The low catches were due in part to a tie-up (during April and May) of much of the U.S. tuna fleet in response to porpoise fishing regulations. Another factor affecting fishing in the ETP was high winds which prevailed all winter in and around the Gulfs of Tehuantepec and Panama and off the west coasts of Nicaragua and Costa Rica. The frequent outbreaks of high winds and rough seas kept the tuna fleet on the move in the ETP looking for suitable fishing areas. During May and June there was considerable tuna fishing activity along the southwest coast of Baja California near a strong north-south SST gradient. By May above normal SST's and related light winds and seas attracted large numbers of tuna boats to an area west of long. 110°W and south of lat. 10°N where fishing was good. However, tuna fishermen east of long. 110°W between lat. 5° and 15°N reported poor fishing from April to mid-June due to an extensive area of high SST's (29°C and greater) that persisted throughout the second quarter.

During most of the period from July to December, tuna fishing on the "Local Banks" off the west coast of Baja California was better than usual because of the above normal SST's and to the strong north-south gradient of SST south of lat. 25°N. South of Mexico and west of Cental America fishing activity was considerably reduced from July to October because of the development of frequent and intense tropical storms. Wind mixing of the surface layers in the path of storms made the location of fish and purse seining difficult from lat. 10°N to 10°S and along the coast to long. 115°W. During the last half of 1977 many tuna boats moved south to an area south of lat. 5°N between long. 120° and 100°W where fishing weather was better than farther north and SST's were in the range 25° to 28°C. This fishing area was probably south of the north Equatorial Counter Current and north of the equatorial ocean front where forage may aggregate and attract large schools of tuna.

Acknowledgments

Data for this report were provided by Fleet Numerical Weather Central, Monterey, Calif. Andrew Bakun made the computations of Ekman transport and upwelling index. Jim Renner contributed plots of atmospheric pressure and winds. Jim Ingraham compiled material on conditions in the Gulf of Alaska as did J.F.T. Saur for the California Current. Forrest Miller contributed material on oceanographic and fishery conditions in the eastern tropical Pacific. Elizabeth Haynes, R. Michael Laurs, and Robert Pedrick reviewed the manuscript and suggested improvements.

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Appendix I

Principal Sources of Data and Information Used:

Atlantic Environmental Group, National Marine Fisheries Service, NOAA, Narragansett, RI 02882. Surface and subsurface temperature data from monthly XBT transects off New York and southern New England. Unpublished reports by staff oceanographers.

Environment Canada, Pacific Environmental Institute, West Vancouver, B.C. V7V 1N6. Monthly means of daily surface temperature and salinity observations from Canadian lighthouse stations. Scattered subsurface temperature observations in Canadian waters.

Fishery Engineering Laboratory, National Marine Fisheries Service, NOAA, Bay St. Louis, MS 39529. Unpublished data on Mississippi River flow and positions of the East Gulf loop current.

National Climatic Center, Environmental Data Service, NOAA, Asheville, NC 28801. Local climatological data: monthly summaries of daily and 3-hourly observations at selected weather stations.

National Environmental Satellite Service, NOAA, Washington, DC 20233. Weekly satellite-observed Gulf Stream analysis charts. Miami SSFS Analysis charts produced weekly.

Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543. Surface and subsurface temperature data and surface salinity data from monthly transects across the Gulf of Maine. Unpublished reports by staff scientists.

Pacific Environmental Group, National Marine Fisheries Serivce, NOAA, Monterey, CA 93940. Sea surface temperature anomaly charts: monthly by 1° square. Computer processed transects of expendable bathythermograph and salinity observations from ships of opportunity between San Francisco, Calif., and Honolulu, Hawaii. Space-time plots of sea surface temperature anomalies for selected 1° squares along the Atlantic coast. Computations of surface layer (Ekman) transport and listouts of data: monthly on alter nate 5° or every 3° grid.

U.S. Army Corps of Engineers Regional Office, New Orleans, La. Mississippi River discharge data.

Appendix II

Publications scanned for environmental or fisheries information:

Mariners Weather Log, (bi-monthly), Environmental Data Service, NOAA, Washington, DC 20235.

Monthly Weather Review, American Meteorological Society, Boston, MA 02108.

National Fisherman, (monthly newspaper), Camden, ME 04843.

Fishing Information, (monthly), Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

U.S. Geological Survey Periodic summaries of streamflow data in various regions in the Atlantic and Gulf coastal areas, issued on varying time schedules by Regional Offices (advance release of data may be arranged by personal communication).

U.S. Naval Oceanographic Office, Washington, D.C. Experimental ocean frontal analysis charts produced weekly from satellite infrared imagery and expendable bathythermograph observations.

Virginia Institute of Marine Sciences, Gloucester Point, Va. Press releases regarding fisheries status.